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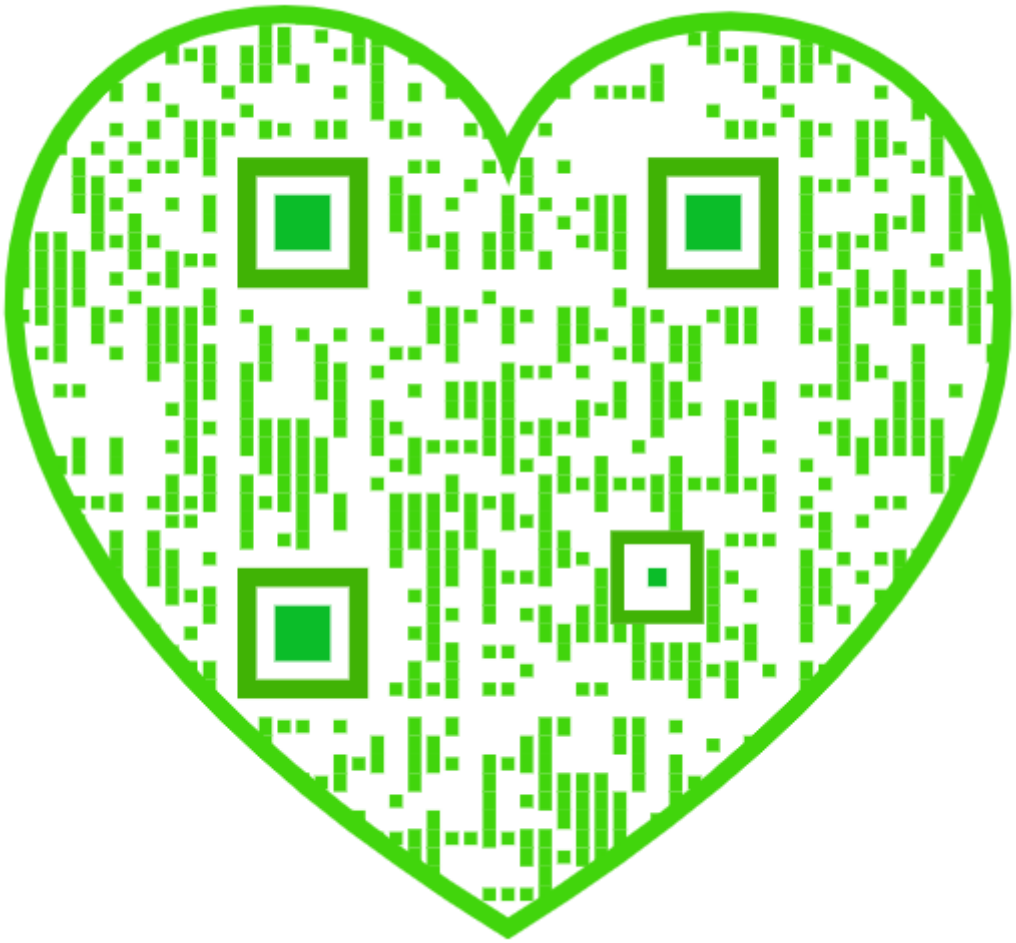
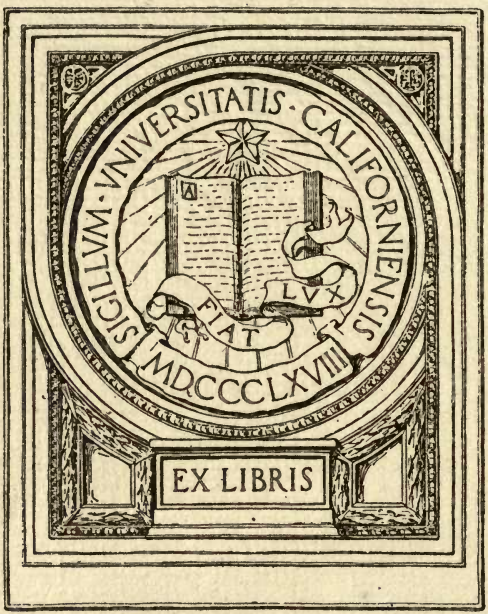
AN INTRODUCTION TO MINING SCIENCE

J. B. COPPOCK

AND

G. A. LODGE

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AN INTRODUCTION TO MINING SCIENCE

LONGMANS' TECHNICAL HANDICRAFT SERIES

AN INTRODUCTION

TO

MINING SCIENCE

A THEORETICAL AND PRACTICAL TEXTBOOK FOR MINING STUDENTS

BY

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WITH DIAGRAMS

LONGMANS, GREEN AND CO.
39 PATERNOSTER ROW, LONDON
FOURTH AVENUE & 30th STREET, NEW YORK
BOMBAY, CALCUTTA, AND MADRAS

1915

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TO

EDWIN TALBOT, Esq., J.P., C.C.

CHAIRMAN OF THE HIGHER EDUCATION COMMITTEE OF
THE WEST RIDING OF YORKSHIRE

IN RECOGNITION OF THE REFORM AND ADVANCE

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PREFACE.

1. The Science Section.

The education of the miner in the scientific and technical aspects of his work is receiving attention from National and Local Education Authorities, from the employer, and what is more promising still, from the miner himself. This has resulted in throwing into the melting-pot old schemes of instruction, in the skimming off the dross, and the introduction of the experimental method into class work. The latter it is felt will sustain interest; it is sure to develop intelligence and correct ideas.

The teaching of science to the miner, adult or adolescent, and to the rank and file of any industry, has got to be considerably changed if it is to grow in popularity. The failure in teaching to connect the fundamental facts of science with the experience of daily life, and to phrase our language in the words of the students' vocabulary, are great weaknesses in our methods. The science side of this book therefore attempts to use the experience of a student as a means of developing a scientific fact, just as the moral educationist uses the experience of daily life in his object lessons to the young.

Questions have been added to each Chapter in this section; the majority have been designed so as to expand the teaching of the text at the same time as they use its information.

JOHN B. COPPOCK.

2. The Practical Application to Mining.

The question of safety in mines is of the greatest importance, and believing that increased safety will be best attained by increasing the intelligence of the miner, the practical part is mostly confined to a simple description of things which are important from the safety point of view.

Extracts from the Coal Mines Act and Regulations and from Inspectors' Reports on accidents in mines are freely given in the hope that lessons will be learnt therefrom and accidents decrease. If the student can be made to realize that great things are built up of little ones, and that only close observation and understanding of details will lead to the understanding of the whole, much will be accomplished.

GEO. A. LODGE.

3. Acknowledgments.

The Authors have to acknowledge their indebtedness to Mr. F. N. Cook and Mr. L. K. Hindmarsh of the West Riding Education Authority, for their valuable help in revision. They have further to thank Miss Coppock for original drawings and Messrs. Longmans, Green and Co. for permission to use many blocks belonging to Newth's and Furneaux's works on Chemistry.

J. B. C.
G. A. L.

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NOTE TO STUDENT.

CERTAIN of the Experiments in this book have a C placed to the right hand of the instructions; it stands for Caution. There is no danger in carrying out these experiments if the instructions are followed and thoughtfulness exercised.

CHAPTER I.

COMBUSTIBLE AND INCOMBUSTIBLE SUBSTANCES.

A YOUNG child acts on the idea that all things thrown on the fire will burn, and so he is inclined to throw on to it not only paper, which gives the looked-for result, but stones as well. As the child develops he begins to realize that stones will not burn, and so there grows in his mind the idea that there are two kinds of things—those which will and those which will not burn. These are most important conclusions, they finally become well established in the child's mind by his experience; and when later on in life the power of reflecting on facts is added to his mental equipment, he finds that the things which burn come from either the animal or plant world, and the things which do not burn come from other sources. The child also begins to see that things burn with different degrees of quickness and more or less flame: paper quickly, but cardboard slowly. A leaf of a tree burns quickly or slowly according to its dryness, often with much flare, and gradually he realizes that when there is quick burning there is more flame than in slow burning.

Experience.

Most people have noticed the quickness of combustion of the floral decorations of a house, e.g. holly, when taken down after Christmas; the rapidity and vigour of the burning suggests that of a piece of celluloid. A very dry leaf burns violently, and dry orange-peel gives little explosions with a big blaze. It is well known that dry holly is more dangerous than freshly gathered holly; in the latter case the combustion is slow and can be easily kept under control, whereas with the dried holly there is a "flare up" at once.

A well-known piece of experience may be repeated to bring out some of the foregoing points.

Experiment.

Strike a match and carefully notice the difference between the quickness in the burning of the head and stick.

There is no doubt that the stick undergoes a slower combustion than the head, and that the rapidity of combustion of the head is more like a small explosion. In fact, sometimes when a match is struck the head bursts very quickly, or suddenly—it is an example of a real but a small explosion. Most boys know that a "squib" after lighting goes off very gently for a few seconds and then finishes with a bang; the bang is due to the sudden heating of a bit of tightly packed powder at the end of the squib. The end all at once ignites, and a small explosion is the result; by all at once is meant that the action instead of taking a second or two is over in a thousandth part of a second. Instantaneous combustion is the very essence of an explosion.

Experience.

A lighted cigarette, cigar, or pipe of tobacco affords an illustration of slow combustion, particularly so when it is away from the mouth. The combustion is made quicker by the action of "drawing through" the burning tobacco.

The last piece of familiar experience should be carefully thought of, so as to understand how the tobacco in each case keeps burning. Air is drawn through the burning mass of tobacco; when the air is drawn through the surface of the tobacco glows with fire, and on ceasing to draw the glow dies down; if left too long the burning ceases. The foregoing is one of the simplest pieces of experience which points out very definitely that the air is in some way connected with the burning of a substance.

Slow and Quick Combustion.

Combustion in many cases may go on extremely slowly and without the production of flame, and there is nothing to show there is combustion, except a higher temperature than the air, e.g. the heat of our body is produced by the slow combustion of our food after it has been digested and

found its way into the stream of blood. The rusting of iron is combustion but much slower than the foregoing, nevertheless heat is produced.

Experience.

Iron railings or other iron structures, if left unpainted, will rust; this leads to the structure gradually wearing away by the falling off of thin layers of rotted or rusted-iron.

A man of science would say that rusting is a process of combustion in which the substance rusting and the air are active; it is very slow combustion, and although heat is produced it is too small in amount to alter the temperature of the structure or to be detected by a thermometer. It is said that in heaps of very thin scrap-iron the heat due to rusting of the iron accumulates so rapidly that the temperature produced has been sufficient to set them on fire. This way of taking fire is an example of spontaneous combustion; because the fire starts without the aid of any outside lighting.

Coal is often stacked in heaps, particularly at collieries and stations, in the open air, and in such stacks spontaneous combustion has been known to occur. It has often been observed that these stacks will blaze up, or smoke, at several parts after a shower of rain. The rain is the cause of letting fresh air into the stack, and as the latter passes in it attacks the coal and produces sufficient heat to start a blaze. In summer time these occurrences are fairly frequent owing to the warming of the coal; stacks are often whitewashed in order to reflect off them the sun's heat and so remain cool.

Gob fires which occur in pits and the firing of hay-stacks afford examples of spontaneous combustion. In all these cases there is an absorption of air by the substance and a production of heat; when the heat makes the substance hot enough it bursts into flame.

The Transforming Action of Heat.

Watch the action of a glowing fire on a piece of freshly thrown-on coal; if the coal is a soft variety it will be seen to form at places a thick tarry liquid and gas; the latter easily ignites and burns.

Thus heat may change a solid into liquid and gaseous substances. It is important to notice that in this case if the liquid and gas were cooled they would not turn back into coal, they have permanently changed.

Experience.

The water as it boils in the kettle turns into steam, which condenses back again to water whenever it happens to cool, as in leaving the spout. Water will in frosty weather become ice.

This experience is so frequent that we are often led to neglect its full teaching and meaning. This latter one differs from the previous piece of experience; it teaches us that the substances, steam or ice, would turn back into water by cooling or warming respectively. The difference is an important one because, although produced in both cases by altering the temperature, the change in the coal is not capable of being reversed; whereas the change of water to ice, or steam to water, is capable of being reversed and the stuff started with reformed.

Experience.

The oil of a burning lamp, or the fat of the lighted candle is turned into vapour, which ascends the wick and burns into gases. These gases mix with the air.

It might be noticed that the candle fat must pass into a liquid before it passes up the wick, but it would be quite impossible after collecting these gases to turn them back into oil or fat. There are plenty of examples, to be found by observation, of changes going on in solid substances—heat turning them into liquids or gases. The most common changes are those where action has taken place and which cannot be undone, so as to re-form the original substance. Let us give a short consideration to the burning of the gas of an ordinary room; the loss of smell undergone in the burning denotes a change. Whatever is formed when gas burns is an invisible substance and therefore is a gas; it must also be incombustible, otherwise burning would go on around the flame. Two substances are formed, as

a matter of fact, odourless, invisible and incombustible. It is plain where the original substance cannot be reformed that the character has been completely changed and substances differing from it have been made. Such changes are very common, and we might speak of them as changes in the composition of a substance; they are technically called chemical changes. A chemical change means an alteration in composition.

Experience.

When a new mantle has been placed in position on an incandescent burner it is set fire to by a match; there is vigorous combustion and an unconsumable mantle left.

This procedure burns off the cementing stuff that stiffens the mantle for transit purposes. This cementing material is very inflammable, and affords an example of fairly rapid combustion.

This common piece of experience therefore affords us an excellent lesson on combustible and non-combustible substances. The non-combustible mantle becomes incandescent, i.e. white hot, by the heat of the combustible gas and therefore gives out light.

There is left behind the non-combustible material of the mantle which in nature is very closely akin to sand, also non-combustible. It may differ in colour from ordinary sand, but the yellow colour of sand is easily removed by acid. In appearance, and in not being combustible, the mantle is much like lime, but it is a nearer relative of the sand family of substances than of the lime family.

The gas, like the collodion which is the cementing material, is changed into invisible substances by the action of heat and air, but the mantle undergoes no change except that it increases in brittleness with use.

It is important that we should fully understand all the actions which go on when a substance is heated; we are apt to regard the moment it takes fire as the beginning, but it is essential that we should know that action is going on before flame and fire show themselves.

Air and Heat.

It has just been stated that heat and air act in changing substances, e.g. gas and collodion. It must be clearly recognized that although they act together and jointly they act in entirely different ways, heat prepares the way for the air's action.

Air does not act upon everything at the ordinary temperature, e.g. it is not until the temperature of coal is $3\frac{1}{2}$ times that of boiling water that the air begins to make it burn. It would be unfortunate if air did attack everything at its ordinary daily temperature, otherwise no structure would be safe. When heat is applied to a body it is the signal for the air to prepare for attacking it as soon as the body gets hot enough.

Robert Hooke, an Oxford chemist, who lived in the seventeenth century, said "the air is the universal dissolvent of all combustible bodies"; by a universal dissolvent Hooke meant that combustible bodies turning as they burn into other substances—gases—disappear from view as they pass into the air.

Robert Boyle, who lived in the same century, specially interested himself in combustion, and he, jointly with Hooke, discovered that candles would not burn in vessels from which all air had been exhausted. It cannot be too deeply learnt that when a thing is completely burnt, the air cannot attack it further, and if a thing will neither burn nor rust, the air is indifferent towards it.

The air's action consists in attacking the different constituents of a substance and changing them. The change varies with the nature of the constituent, e.g. one constituent of coal gas is called hydrogen gas, and every double particle of the latter gas is attacked by a single particle of the active constituent of the air; they all become fixed firmly together and do not again separate. Another constituent of coal gas, called marsh gas, behaves differently; its five-fold particle splits up during burning, dividing itself into three parts, each one of which takes up a single or a double particle of air. The original particles may be illustrated by diagrams, which are correct in number of particles but grossly exaggerate the size of the particles :—

Double hydrogen particle.

Five-fold marsh gas particle.

Double oxygen particle (the air's active constituent).

When the attack of the air upon the particles of any substance commences heat is produced; the active constituent of the air showers its particles violently and at a great speed upon the substance making it hot. The action is very similar to the blacksmith's hammer raining its blows on the anvil; both anvil and hammer become hot, but there is this difference that when a particle from the air strikes a particle of any substance and produces heat these two particles become at once firmly adherent.

That heat is continually produced when coal gas is burning requires but little effort on our part to recognize. Heat is continually produced as the active particles attack the gas particles and this turns the issuing stream of gas into flame at the gas jet.

Experience.

To start the burning of gas a lighted match is applied. This starts the burning and then any more gas streaming out is ignited by the burning portion; it takes the place of the lighted match.

The flame is handed on to the stream of particles coming along the gas pipe as they appear at the gas burner, they get heated by the gas just burnt, and at once start burning.

Compare the action with the idea expressed in Henry Newbolt's lines on the words "Play up":—

> Bear through life like a torch in flame,
> And falling, fling to the host behind.

It is necessary to carefully distinguish between heat and air; the latter consists of particles which have weight, and in the burning of gas its weight is increased by the gas particles taking up air particles.

Heat is not a substance; it is a rapid trembling of the par-

ticles of a body, and when the body is cool the particles have returned to a fairly quiet and placid condition. If they became quite motionless, entirely at rest, the body would have no heat in it and therefore no temperature. This latter state has never been completely reached in any substance.

There is no difference in weight between a body hot and the same body cold, unless in the heating the air has attacked it.

It is often said that "heat can be seen rising," as in the waviness that can be seen over a lighted gas or a heated metal surface, e.g. railway lines. As the air comes into contact with hot gas or rail it gets heated and rises; it is the heated air which can be seen.

Experiments on Combustible and Incombustible Substances.

1. Heat in the Bunsen flame (Fig. 1) a length of the following wires: platinum, iron, and copper. See if the glow of the wire varies at different parts of the flame. Try and estimate the temperature of the glowing wire by its colour, using the following table :—

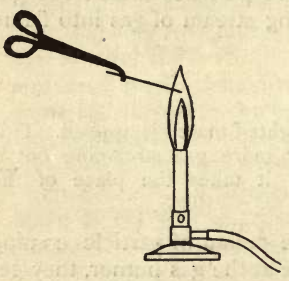

Fig. 1.

Rough Estimation of Temperature by Colour.

Glow just visible, 520° C.; dark red, 700° C.; cherry red, 900° C.; bright cherry red, 1000° C.; orange, 1150° C.; white, 1300° C.; dazzling bluish white, 1500° C.; electric arc, 3500° C.

2. Ignite a 2-inch length of magnesium wire holding it in the flame by crucible tongs, and compare the result with those obtained in the previous experiment.

There is neither gain nor loss of material in the case of the platinum wire, as could be shown by weighing before and after the experiment, and there is no colouring of the flame. The platinum wire undergoes but one change, and that a temporary one; it glows or becomes incandescent.

The copper and iron wires will undergo further changes than that of glowing, e.g. the copper will blacken. These changes will be permanent, and more easily seen by comparing pieces of heated and unheated wires. If a vapour comes from the wire it may, or may not, influence the colour of the Bunsen flame. Copper vapour gives a distinct green colour to the flame.

The Burning of Magnesium Wire.

This metal when heated in air burns with a dazzling white light, largely used in taking flash-light photographs. It should be noticed that the burning of the metal continues after its withdrawal from the flame. The Bunsen supplies the heat required to start the action, but that required to continue the burning is supplied by the violent action going on between the metal and the air.

When the light of the burning magnesium has died away, there remains a white substance having the original shape of the metal. Compare its properties with that of the original metal; it is a white substance instead of a lustrous metal; a fragile body instead of a tough one. A piece of this white substance held in the Bunsen flame may be seen to glow in the dark, but it does not give out a dazzling light nor undergo combustion.

The differences in the action of heat upon platinum, copper, magnesium, and iron compels us to arrange all changes into two classes: temporary changes and permanent changes. In a permanent change the substance changes its composition; either something is removed or added, it is plain that weighing the substance before and after the experiment will tell us which has happened. Iron, copper, and magnesium permanently change by heating, but platinum remains unaltered after withdrawal from the flame.

Experiments on Solid Substances.

Heat a piece of the following substances, holding them by the crucible tongs, in the hottest part of the flame (Fig. 1); notice any effects: lime, asbestos, coal, coke.

Asbestos and lime will glow to a moderate extent in the Bunsen flame, the asbestos may even show signs of fusing, but in neither case will a vapour be given off. They are examples of incombustible substances which may be raised to incandescence by heat. Gas fires which have the gas flame playing on pieces of asbestos leave them unburnt. The lime cylinder on which the hot flame plays in the oxy-hydrogen flame of the optical lantern is unburnt, it shows the incombustibility of lime. The oxy-hydrogen flame has a temperature of 2800° C., it raises the lime to a white-hot incandescent state but does not burn it. A brilliant white heat can even be produced at 1500° C., or about half that of the lime cylinder in the oxy-hydrogen flame.

Asbestos contains, as constituents, lime and also the white substance formed when magnesium burns. The two foregoing substances along with sand, which is an infusible substance, are the three constituents which have been worked up by nature into the material called asbestos.

The action of heat on coal and coke is different from the foregoing; the general experience of the student should be utilized in interpreting the action. Coal will give off gas and smoke as it does on the fire, the former being very easily ignited. Coke being coal from which all fumes, gas, and smoke have been driven off will only glow. If the coke is made red hot then it may burn and give off flame, but the flame will be distinctly different in appearance from the flame of coal.

Experiments on Substances.

Warm separately and gently a small quantity of each of the following substances in a porcelain dish resting it on a tripod or as shown in Fig. 2: petrol, benzine, petroleum, vaseline, paraffin wax. Try and ignite their vapours. Hold a glass rod in the burning vapour and note any result. C

The five foregoing substances are chosen because they belong to the same family of compounds as marsh gas, this being the dangerous constituent of fire damp. By a family of compounds is meant a number of individual substances which behave similarly in their ways and made up of the same constituents. This paraffin family, of which there are

many members, resemble one another in inflammability or combustibility.

Marsh gas is a gas, as its name implies, and if mixed with air possesses combustibility and explosive power. One-third of coal gas consists of marsh gas, and as a combustible and explosive substance, when mixed with air, coal gas is well known.

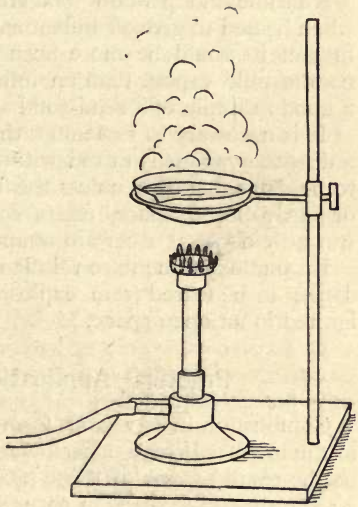

FIG. 2.—Apparatus for warming small quantities of an inflammable liquid.

Petrol, benzine or benzoline, and petroleum are liquids, and therefore heavier, bulk for bulk, than marsh gas. Petrol and benzine are more dangerous than petroleum, because they easily pass into vapour which by mixing with air becomes inflammable, and would in a confined space have explosive power. If air at the ordinary temperature is passed over petrol the latter evaporates, and a mixture of air and petrol vapour is obtained; this is explosive. This mixture is applied and used in petrol engines where the explosion, i.e. the firing of the charge of vapour and air, is started by an electric spark.

The proportion of petrol to air in the mixture is about nine of air to one of petrol.

Petroleum does not give off a vapour as easily as petrol, but its explosive power is often exemplified by lamp explosions in houses. This is on account of its vapour mixing with air in the reservoir of the lamp, and getting over-heated in some way, it fires and shatters the lamp. Suppose a wick is loose in its lamp fitting or metal chamber and by reason of its shortness it is not dipping into the oil. The wick, unless

thoroughly extinguished, may burn down in its fitting and so fire the mixture of air and vapour in the reservoir, the air having found its way into the reservoir by the bad fitting of the wick in its metal chamber.

Vaseline and paraffin wax are substances still less liable when heated to give off inflammable vapour than petroleum; in fact it would be more accurate to say they give off a combustible vapour than an inflammable one. Vaseline is a good example of a semi-solid substance.

It is necessary to remember that explosions cannot occur unless the vapour is mixed with air, and they are not likely to be damaging ones unless the firing takes place in a closed, or partly closed, space, e.g. a room or a mine. Then they can only occur at a certain temperature.

In our experiments on inflammable bodies there is no danger to be feared from explosions because the vapour is ignited in an open space.

Practical Application to Mining.

Combustion in its various forms is continually taking place in the mine. It may occur by accident or design, or it may be the result of one of those processes of change which are constantly taking place in nature's laboratory. Let us consider these causes separately.

The accidental burning of inflammable material, such as candles or waste, or the production of a spark, due to a defect in some of the electrical arrangements of the mine, may cause the timber supporting the roof to take fire and possibly the coal itself, with disastrous results. Fires in mines may have very serious consequences; they are very much dreaded by those who take part in the management of collieries. In addition to the danger from the fire itself, there is danger of suffocation by smoke, of being poisoned by inhaling the gases given off from the fire, and lastly, the danger from falls of roof caused by the burning of the timber supports.

A few examples of serious underground fires caused by accident may be given. In 1908 a fire occurred at Hamstead Colliery, near Birmingham, and twenty-five lives

were lost. The miners at this colliery worked by the light of candles, and the fire was caused by the carelessness of a miner who on taking his supply of candles from the candle box at the pit bottom, burned off his bundle instead of cutting it, placed the smouldering wick back into the box and set on fire the whole of the candles in the box.

In 1909 accidentally setting fire to a load of hay was the cause of a great disaster at the Cherry Mine, Illinois, 250 lives being lost.

In 1911 a fire occurred at Pinxton Colliery, Derbyshire, which was caused by the fusing of an electric cable in a pump-room in the side of the shaft, setting fire to timber and coal. The smoke from the fire was very pungent. The fire was fought by men wearing rescue apparatus and eventually got under control, the 411 men underground being got out safely.

Regulations under the Coal Mines Act, 1911, require: "That no person shall allow any burning wick or part of a wick or other burning material to lie about in the mine, and every workman on leaving his working place shall take his light or lights with him".

Where candles are used they must not be stored in the mine. "All candles used in the mine shall be placed in a metal holder which shall be of such a design that when fixed to a prop the flame of the candle cannot set fire to the work." "Candles looped or strung together shall in no circumstances be burned off below ground."

"In any mine or part of a mine in which safety lamps are required by this Act or the regulations of the mine to be used, no person shall have in his possession any lucifer match nor any apparatus of any kind for producing a light or spark except so far as may be authorized for the purpose of shot-firing or re-lighting lamps as authorized by an order made by the Secretary of State, or any cigar, cigarette, pipe, or contrivance for smoking."

The regulation dealing with matches and smoking contrivances is a very important one. A large number of persons are prosecuted every year for breaches of this regulation, and a number of accidents have been due to this cause. It is very probable that the majority of persons who offend

in this way are quite innocent of any intention to do so, but this fact only proves the need for the greatest vigilance on the part of the management of the colliery and by the workmen themselves.

One or two examples from reports of Inspectors of Mines showing how unconscious breaches of the regulations might have had very serious results will be both interesting and instructive.

Some miners found a jacket smouldering as it hung in a gateroad. The fire had been started by matches which had slipped down into the lining of the coat.

An undermanager on going into a slit connecting the intake and return airways, where workmen hung their clothing on nails driven into wood battens resting on brick side walls, discovered the remains of a jacket which had become ignited. The jacket was hanging on a nail, and close to it, on the floor, were the remains of another jacket in a red glow. The latter had evidently been the first to take fire and had set fire to the former with which it would be in contact when both were hanging up. The battens into which the nails were driven had taken fire, and very serious consequences would probably have resulted if the fire had not been discovered. The owner of one of the jackets admitted that he smoked on the way to work but left his pipe at the surface and as no trace of a pipe was found in either coat, a probable explanation of the occurrence seems to be that some smouldering ash from the pipe must have remained in a pocket of his jacket.

Combustion is necessary and desirable for giving light to the miner, but the use of candles and lamps should be attended with the greatest care so as to avoid accident. In shot-firing we have another example of necessary combustion, and in this case also careful precautions should be taken.

A very important class of mine fires—those due to spontaneous combustion—are dealt with in another chapter.

QUESTIONS.

1. Explain why the incandescent gas mantle and the carbon filament in an electric lamp do not burn away by using.
2. A man smokes a cigarette, cigar, or pipe by drawing air through

it. Will there be any differences in the air's composition before and after the drawing through; if so, what are they?

3. A small electric fan is revolving quickly, and it is found that as a glowing match-stick is brought towards it the colour of the glow changes from red to yellow. Explain it.

4. Draw up a list of substances which may be easily ignited, and another list of things which cannot be ignited. Then draw up a list of things which are between these two extremes.

5. Which of the following phenomena show incandescence without combustion?—

Molten iron as it flows out of the furnace.
A red-hot platinum wire.
A red-hot poker.
An asbestos gas stove red hot.
A coal gas flame.

6. In South Wales some people mix clay or lime with fine or small coal making a ball of fuel. What part of the ball is useless as fuel, and why?

7. What combustible substances are taken down the mine every shift by the miner? Are clothes saturated with lamp oil likely to be dangerous in the mine?

8. A man with heavy nails in his boots accidentally kicks a stone in the mine and produces a shower of sparks. How do you account for their being red hot? Is such an action dangerous in a mine?

9. Which would be the best wire for making a gas mantle identical in shape with the common mantle?

10. Is a red-hot fire incandescent? Does it differ in any way from a red-hot Welsbach mantle?

11. Why are dishes used for evaporating liquids, as in Fig. 2, made of porcelain? Is there any advantage in having a glaze on them?

CHAPTER II.

THE AIR: ITS CONSTITUENTS AND ITS ACTIONS.

It is a very common custom to blow a fire if it shows signs of going out, the blowing being done by the bellows or by the mouth. This helps the fire to burn more vigorously, but at times it has to be blown with care. If there is but little red-hot coal in the fire, and this of a dull red colour, then it is possible that strong blowing will put out the fire—the cold current of air takes away heat and so the red glow may disappear. In general circumstances if we start blowing gently the glow increases and passes from a dull to a bright red, and then even with vigorous blowing the coal gets well alight, but all the time the cold air has been robbing the fire of heat. The pouring of a stream of air on the fire tells us that the air is in some way helpful to combustion, for the fire increases in brightness despite the cold air taking away some of its heat.

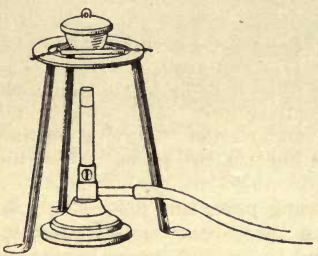

Fig. 3.—Apparatus for showing that exclusion of air stops combustion.

Experiment.

Heat a bit of wood charcoal in a porcelain crucible supporting it on a tripod by a pipeclay triangle; have no lid on the crucible and observe what happens; take the time it requires to burn away completely. It will be completely burnt away as soon as the black colour has disappeared. Heat a similar amount well covered with sand the same length of time. Remove the sand and compare the result with the previous one.

Robert Hooke, the Oxford chemist, performed a similar experiment in 1665, and he found that the charcoal remained unconsumed when there was no free access of air, but, as Hooke said, "when it comes into contact with free air it readily burns away".

Underground fires when removed from the pit in tubs are covered by a layer of sand.

Cutting off the Air Supply.

In schools scholars are instructed that if their clothing should catch fire the best thing to do is to lie on the floor and roll rapidly over and over, perform what a child calls "roly-poly".

If there happens to be any good-sized covering at hand, e.g. a rug, carpet, blanket, or coat, then it should be wrapped round the burning child by anyone present, then laying the child on the floor roll it over and over gently.

Now it is plain that this is putting a visible wrapper round the body so as to keep the air from the burning clothes and so smother the fire.

Further experiments must be made to prove that the air is concerned in combustion.

Experiment.

Take a bottle containing phosphorus, and note the presence of water. C

The best method for obtaining a bit of phosphorus from the bottle is to invert it on the hand and withdraw a piece, which should immediately be placed in water in using a porcelain dish; also fill up the bottle again with water. Cut with a knife the piece obtained, keeping it under water. Having obtained a small piece of the substance cut it in two parts. All cutting must be done under water.

Dry one part quickly by blotting paper and place it in a dry vessel, the other part leave in the vessel containing water. Notice any action which goes on in the vessel where the phosphorus is surrounded by air. Write down any inferences you may draw from the experiment.

The experiment teaches us that white fumes come from the phosphorus which is surrounded by air. If the experiment is allowed to continue for a length of time the

vessel would fill with fumes. The air is attacking the phosphorus and the white fumes consist of a new substance made from the air and the phosphorus.

The water in the second vessel cuts off air from the phosphorus and there is no action.

You should now be in a position to give reasons for the method adopted in cutting and storing phosphorus.

Lavoisier, an illustrious French chemist, satisfied himself by experiment in 1774 that some part of the air is absorbed by phosphorus when it fumes or burns.

Experiment.

Collect a vessel full of coal gas, by holding the inverted vessel over an unlit gas burner, then quickly introduce a lighted taper. Notice carefully the action of the gas on the lighted taper.

The vessel is held upside down on account of the gas being lighter than air. The gas burns at the mouth of the vessel where there is air, but the taper, which burns in air, is extinguished as soon as it is thrust into the coal gas.

The experiment therefore in a three-fold way shows that air is necessary for combustion.

Experience.

The blacksmith in reviving his fire blows air through it. The house fire has its ashes poked away so as to brighten it up by letting in air. The gas used for lighting purposes burns only when it has passed the gas nipple and comes into contact with air.

Smothering Flame by Excluding Air.

If a lighted taper or match is introduced into a vessel containing a jar of carbon dioxide gas the light is extinguished or smothered.

If a lighted match or taper or other lighted thing could be put into a gasholder there would be no explosion, the light would go out. As there is no air there can neither be ignition nor combustion.

Experiment.

Place a piece of washing soda or a bit of limestone in a gas jar, then add some dilute acid. Effervescence at once begins,

due to carbon dioxide gas being liberated from the solid put in the jar. Keep the jar covered until the effervescence stops, then put a lighted taper into the jar; the light is extinguished.

The gas surrounds the light on all sides, the air supply is entirely cut off and therefore combustion stopped. Compare this with the similar experiment with coal gas on p. 18.

Experience.

It has fallen to the lot of most people to take off the kettle lid and look inside, using a lighted match to see if the water is boiling. If the water is hot the space above it is filled with water vapour and the light is immediately extinguished.

The lighted match is cut off from the air supply and it cannot therefore continue to burn. The action of water vapour or carbon dioxide or coal gas is precisely similar to surrounding a burning body by a tight-fitting covering; the air is kept away by the invisible gas, or the visible covering and the combustion is stopped.

Smothering a Fire by Water Vapour.

How does water act in extinguishing a fire? Does its vapour help in the action? Help is given in two ways: the heat of the fire converts the water into vapour and the burning body gets surrounded by a cloak of it. In this way as water vapour does not support combustion the fire is smothered, i.e. it can get no air. The space around the burning body is crowded with particles of water vapour and there is no room left for air particles, so burning cannot continue.

Apart from the smothering action there is an abstraction of heat from the thing burning as soon as water is thrown on it, and this tends to stop the burning. The heat abstracted is partly used up in making the water hotter, and partly in turning some water into steam.

Smothering a Lamp.

If a miner finds himself in an atmosphere containing "gas" and it begins to burn in his lamp, he should not attempt to blow it out because he is feeding it with air.

The lamp should be smothered by covering *all* air holes with cap, coat, or any other available covering; this effectually "smothers the lamp" by cutting off air which is vital to burning.

Experiment.

Take a lamp glass and fit half way into the lower end a cork from which about one-third of its area has been removed as wedge-shaped pieces around the circumference. Fix a short piece of candle on the cork, either by melting the wax or a nail penetrating the cork and candle.

Light the candle and note any tendency to smoke or any unsteadiness of the flame. Now fit the lamp glass on the cork and see if any differences show themselves in the flame.

Cover the upper end of the lamp glass by a cork or other covering, and close by a cloth the openings in lower cork. Notice that the flame is extinguished.

The effect of the lamp chimney is to draw a current of air through it. This produces a greater brightness of the flame, and the tendency of the candle to smoke disappears. The air is drawn around the flame and this brings about more complete and intense combustion and more light. The current of air also brings about the complete combustion of the smoke; it may be too strong, i.e. too rapid, and the brightness of the flame is therefore lessened, the yellow area being decreased.

Experiment.

Take an oil lamp and light it. Partly close the chimney top by moving a piece of cardboard above and across it; see if a position can be obtained where the flame emits more light. If there be such a place the chimney normally causes too much draught.

The stoppage of the air supply by placing the cardboard on the top of the lamp glass would cause the extinction of the flame.

Experience.

In the lighting of an oil lamp the increased brightness of the flame may be seen immediately the chimney glass is placed on

the lamp. The blocking up of the air holes by dust, dirt, and oil is known to affect the light-giving power of the lamp.

Boyle and Hooke's experiment, that candles would not burn in vessels from which all the air had been extracted, is not an easy matter to repeat, but a modification of it may easily be performed.

Experiment.

Take a glass vessel called a bell jar, and stand it on the bottom of a vessel, which should be large enough in diameter to allow the bell jar to stand in it; fix in a 3-inch piece of candle as shown in Fig. 4. Place a layer of water about 2 inches deep in the vessel, light the candle, and put over it the open bell jar, and then tightly fix in the stopper. Notice any effects on the light of the candle, repeat the experiment to see if these effects again happen.

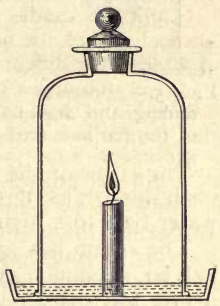

FIG. 4.—Experiment to show that air is necessary for combustion.

It is necessary to notice that in the bell jar a small portion of air has been cut off from the atmosphere, and although the candle starts well lighted it is soon extinguished.

If we removed the stopper of the bell jar and passed a tube from the outside air through the water and under the jar into the space where the candle is, and lighted the candle again, it would not go out. It would have been given a continuous supply of air and therefore continue to burn. We understand now why a miner's lamp is always provided with openings; it is to allow a stream of air to pass through and so keep the oil burning.

It is necessary to consider further this stoppage of the burning of a body when shut up in a small quantity of air. The same result will happen to other bodies. Some explanation of the result must be found.

Experiment.

Use the apparatus as shown in Fig. 5. Cut under water a small piece of phosphorus, about the size of a pea, and then C

dry it quickly between blotting-paper. Place it in a small porcelain crucible which will float on the water in the bottom vessel. Over this floating crucible containing the phosphorus place the open bell jar and then replace the stopper. Notice that the water inside and outside the bell jar is at the same level. Mark this level outside by a strip of gummed paper. Heat a long piece of glass tube, or wire, and removing the stopper touch the phosphorus with the heated end. At once withdraw the tube or wire, and replace the stopper. Notice all that occurs.

FIG. 5.—Apparatus for finding the amounts of oxygen and nitrogen in air.

The phosphorus burns fiercely, but finally goes out, and the jar is filled with white fumes. Leave the jar to cool, notice as it does so the fumes disappear and the water rises to a higher level inside the jar.

The action has apparently resulted in a loss of air to the bell jar, inasmuch as the water stands at a higher level; there is now less space occupied by the air in the jar.

In a particular experiment it was found that the jar to start with had 140 cubic inches of air in it: after the action was over and the jar again quite cold the gas left in was only 112 cubic inches, so obviously 28 cubic inches had disappeared.

Continuation of the Experiment.

When the vessel is cold and the fumes have dissolved in the water notice that the water has risen inside one-fifth of the height of the jar. Now bring the outer level of the water up to the inner level by adding water. Introduce, after removing the stopper, a lighted taper into the bell jar and notice it is quickly extinguished, or try and re-ignite the phosphorus in the crucible; it will be found to be impossible. Replace the stopper again.

The bell jar now contains an invisible gas which will not allow a taper, nor the phosphorus, to burn in it. Although

like air in being invisible, it is unlike it in not allowing bodies to burn. This invisible gas is a constituent of the air and amounts to four-fifths of the whole. Air, therefore, consists of two parts of which only one supports burning.

It appears, then, that air is made up of two gases, one supports the burning of the phosphorus, but is used during the burning and then the burning stops The second, which is plainly the larger part of the air, will not allow the taper nor phosphorus to burn in it, and so is left untouched.

The figures given on the preceding page will help us to find the relation between the amounts of the two different gases which make up air; they show that one-fifth of the air disappears and four-fifths are left untouched. This we should find to be approximately the case in the experiment performed. Lavoisier called this gas, which takes part in the burning of substances, oxygen; the name means acid producer because many substances burning in air take up oxygen and produce acids. The inactive gas which is left behind is called nitrogen, a word that means nitre producer. Nitre is very largely used in explosives.

The experiment detailed above will give fairly accurately the relation between the volumes of oxygen and nitrogen, it ignores small amounts of argon, carbon dioxide, and moisture. See p. 37 for further details of substances in air.

Further Knowledge of Oxygen.

Joseph Priestley, a native of Birstall, Yorkshire, discovered oxygen in 1774 in the substance called red precipitate; he called it fire-air.

By using a powerful "burning glass" he found that when the solid substance called red precipitate was *strongly* heated a gas came off. In this gas a candle burned brilliantly, and some mice put in it became very active in their movements. In the same year Scheele, a Swedish chemist, independently discovered oxygen by heating nitre, he may have preceded Priestley in the discovery of it.

Experiment.

Take a hard glass tube, place in it a small quantity of the substance called red precipitate, now called oxide of mercury, and then strongly heat it; hold at the same time in the upper part of the tube a glowing splint of wood, and notice that the glow will burst into flame as the oxygen, after splitting away from the mercury, passes up the tube (see Fig. 6).

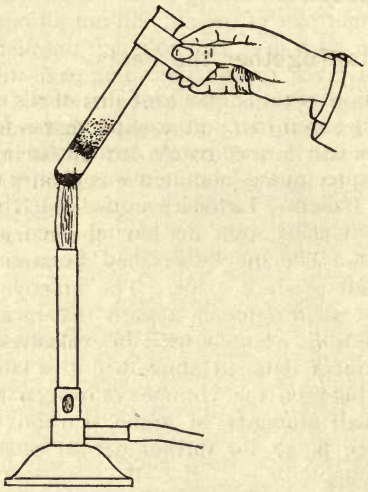

FIG. 6.—Breaking up "red precipitate" by heat; notice the mercury collecting on the tube.

Free and Bound Oxygen.

The oxygen in the air is mixed with nitrogen, the particles have a free and independent existence. The oxygen in the red precipitate is united to mercury; both mercury and oxygen are in bondage to each other, and great heat is required to break up this bondage. This bondage is technically called chemical union.

In rusting and burning we have free oxygen attacking a substance with the result that this free oxygen enters into bondage with the rusting or burning substance; in this state of bondage oxygen is not capable of helping either rusting

or burning. Only when it is free from bondage can it take part in attacking a combustible substance.

Bondage or chemical union, therefore, brings about a change in the actions of a substance; it considerably restricts its activity.

These ideas of free and bound oxygen are of great importance. Bound oxygen cannot support combustion, it must be liberated first.

Lavoisier puts Together the Facts.

Lavoisier was shown the results of Priestley's experiments. He had himself found that red precipitate was formed when quicksilver (mercury) was *gently* heated in air, and the weight of red precipitate obtained was greater than that of the quicksilver taken. Lavoisier argued that the gain had been brought about by some air having been absorbed by the quicksilver. The quicksilver had been rusted by its heating in the air.

Lavoisier was the first man who gave a true explanation of rusting and burning; in each case the oxygen of the air is attacking the body and changing it. In rusting there is generally no flame produced but there is heat; as rusting goes on little by little so the heat is produced little by little. In rusting the body changes its appearance but remains a visible thing. In burning there is a fierce attack between the oxygen and the burning body; heat is liberated in big quantities, flame is produced and the body disappears as gases into the atmosphere. The conclusion has been reached that oxygen is the great supporter of combustion.

Lavoisier also proved that during burning the body is not destroyed, but only altered in nature. Soot, smoke, and ash are a few visible evidences of the alteration; the great portion of the body goes into the air and becomes invisible gases.

As oxygen is necessary for the combustion of bodies it is interesting to know the amounts of oxygen which there must be in air for combustion to continue. The following figures show the amounts of oxygen left in air when the bodies named will no longer burn;—

Candle goes out when oxygen is reduced to					17	per cent.
Petroleum	,,	,,	,,	,,	17	,,
Marsh gas	,,	,,	,,	,,	$17\frac{1}{2}$	,,
Coal gas	,,	,,	,,	,,	$11\frac{1}{2}$	,,
Phosphorus	,,	,,	,,	,,	0	,,

Oxygen is vital to life just as it is to burning; there can be no life without free oxygen; it gets into the lungs by our breathing air, from the lungs it finds its way into the blood and so goes wherever a blood vessel is carrying blood. In the case of breathing it is found that the oxygen may be decreased in the air breathed to 14 per cent, and yet it is just as good as ordinary air which contains 21 per cent.

It is plain then that when the candle or light goes out in the mine for want of oxygen the air is still fit for a man to breathe without danger. Miners who therefore think they have had a narrow escape after passing along a road which extinguishes their light may thus be deceived, but such an atmosphere should be considered dangerous.

Substances Formed by the Oxygen's Attack.

As there are many common combustible substances, e.g. coal gas, candles, oil, and coal which disappear during their combustion, it is necessary to find what substances are produced in these changes and their influence on the purity of the air. Further, are there any substances which might be regarded as pre-eminently combustible substances; in short, what is it the oxygen attacks with so much fierceness when heat and flame are produced?

When a body burns it usually completely disappears. We shall therefore have to deal with invisible things, and some means must be devised to render them visible so as to prove their existence.

Experience.

It is not difficult to notice that when certain substances burn moisture or water is formed. A kettle of cold water or a flat iron placed on the gas stove soon has its under surface covered with moisture. The chimney glass just after being placed on the lamp or gas burner shows a mist on its inner surface. In shop windows

the glass often shows moisture inside when the gas is lighted, and the temperature of the outside air is low.

The explanation of the foregoing experience is that water vapour is formed when gas or oil burns and condenses on a cold object. As the burning goes on it heats the body so much that no moisture can stay on it, and it therefore becomes dry; moisture is still being formed but the body has got too hot for it to condense to water.

Experiment.

Turn on the gas and unlighted (see Fig. 7) show that no moisture is deposited on a clean, dry and bright glass vessel held over it. Light the gas and hold the same vessel high above a small flame; moisture will be at once deposited on its surface.

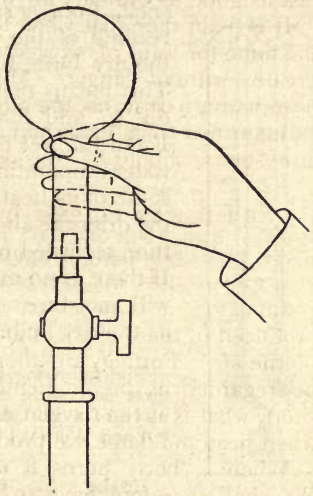

Fig. 7.—Experiment with coal gas.

Gas, candles, oil lamps, fires and human beings give off moisture or water vapour. This may be proved by using the same vessel in a clean, dry condition. We should expect to find, with so many sources making it, water vapour as a constituent of the air apart from its origin as rain.

In all these combustible substances there is a constituent called hydrogen. This substance is attacked by the oxygen and both get bound together. Moisture is made by the binding together of oxygen and hydrogen particles. Both are gases when free, but united they form that very common substance water.

Water vapour in the atmosphere is largely derived from water surfaces, such as rivers, seas, etc.; the amount added by combustion and breathing of human beings and animals is very small in comparison. On the other hand, in closed

places, such as mines, rooms, etc., the amount added to the air by combustion and breathing is of the greatest importance.

The average amount of water vapour in the air is 1·5 per cent, i.e. 1½ cubic feet in 100 cubic feet of air. It is spread uniformly throughout the air. The amount of water vapour in the air may be found by an instrument called the wet and dry bulb thermometer—there is one kept at every colliery, so make yourself familiar with it if possible.

Fig. 8 shows the instrument; it consists of two thermometers, one of which—called the wet bulb—has its bulb constantly wet by drawing up water, along a wick, from a small bottle. Notice that the reading of the wet bulb is lower than that of the dry bulb, 52° F. and 60° F. respectively. This means that the temperature of the air is 60° F., and that the lower temperature, 52° F., of the wet bulb thermometer is caused by water evaporating off the bulb and taking away some of its heat. The greater the evaporation the drier the air is, and the lower the temperature recorded on the wet bulb thermometer. If there is no evaporation then the air is filled with moisture and the wet bulb reads the same as the dry bulb.

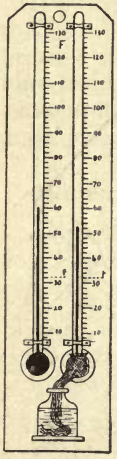

FIG. 8.—Wet and dry bulb thermometer, or hygrometer.

The following hygrometer readings were taken on three successive days in the Intake and Return Airways of a Yorkshire pit. The readings of the Dry (D) and Wet (W) bulbs are in Fahrenheit degrees:—

	D.	W.	D.	W.	D.	W.
Intake .	51	47	58	53	54	49
Return .	73	68	75	73	73	68

Water vapour in air is of some importance because it produces a feeling of discomfort and stuffiness. If the "wet bulb" of the hygrometer in a pit shows a temperature of 70° F. there is much moisture present, and the mine, or a room, will be uncomfortable to its inhabitants, but dry moving air at 90° F. would be satisfactory to anyone working therein.

Watering the roadways of mines increases the amount of

water vapour in the air and this decreases a man's capacity for work, particularly if the temperature is high.

Moisture is a waste product in the processes known as burning and living; it is not the only one. Another substance is an invisible gas which does not easily turn into a liquid as water vapour does, and so we get no familiar or simple indications of its presence in air.

Experience.

Many substances withdraw moisture from the air and so in time become moist, e.g. impure table salt. Other substances, e.g. lime water, withdraw carbon dioxide from the air. If lime water is kept in an unstoppered bottle or an open vessel, a thin white crust forms on its surface. Also lime mixed with water, as used for lime-washing, will after standing in a bucket show a white skin or layer on the water surface.

The formation of this thin white layer is due to lime withdrawing carbon dioxide gas from the air; it is formed in the following experiment.

Experiment.

Take a small glass vessel and pour into it a ½ inch layer of clear lime water, then allow it to stand exposed to the air; a thin whitish layer will be formed on its surface.

Lime water consists of lime dissolved in water. The lime in it absorbs from the air the gas called carbon dioxide or carbonic acid, and from the two substances the white layer, called lime carbonate, is made. The name is intended to denote it is made of lime and carbon dioxide.

The explanation is that the carbon dioxide particles in the air are caught and fixed by the lime particles dissolved in the water, and the two form on the surface a layer of white substance called carbonate of lime.

The layer of air over the surface of the lime water has carbon dioxide particles in it, and as they are taken out by the lime particles fresh ones come from the upper layers of air to take their places, and these in their turn are seized by lime particles. One particle of lime can only seize one particle of carbon dioxide.

This explanation should help to show us that the particles

of carbon dioxide are not at rest; there is movement until they get seized by the lime particles, then as they form part of a solid film they lose their power of wandering.

If lime water be kept in a well-stoppered bottle no film is formed. There will be a few carbon dioxide particles in the air above the liquid, but their number is so few that they are insufficient to form a film.

A Test.

When it has been found that an action accomplished by one substance is not done by any other substance, then whenever this action occurs we may be quite certain that this one substance is doing it. Carbonic acid is the only thing that will form this white layer with lime water, and therefore we speak of lime water as a test for carbonic acid because it affords a means of detecting the latter.

If we were to breathe upon some clear lime water a layer of carbonate of lime would be formed. If an arrangement were made to lead the air coming away from the burning of oil, gas, candles, etc., into contact with clear lime water, the same substance, lime carbonate, would be formed. There are some very simple ways of showing that combustion and breathing result in the production of carbonic acid.

Experiments on the Products of Breathing.

1. Breathe on a cold clean glass surface; a film of moisture will be distinctly seen.

2. Fill a cylinder with water and invert it into a basin of water; now take a piece of glass tube, place one end under the inverted cylinder, and empty the lungs by blowing through it. See Fig. 9.

Add a small amount of lime water to the expired air in the cylinder and shake gently when the white substance will be obtained.

A Simple Way of Applying the Test.

Take a length of glass tubing, say 6 inches, and place one end in a beaker or vessel which contains a layer of lime water. Blow through the lime water and notice it becomes white owing to the carbonic acid in the breath forming, with the lime, carbonate of lime.

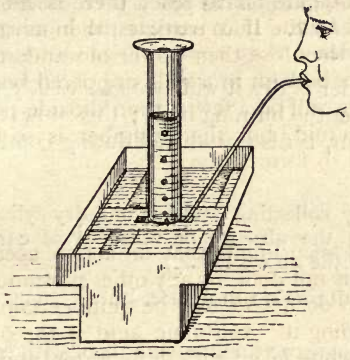

FIG. 9.—Collecting a cylinder of expired air by displacing water.

The Products of Combustion.

Show that any burning body, e.g. gas, candle, oil, taper, match, gives off carbon dioxide. Hold a cylinder over the flame, but not

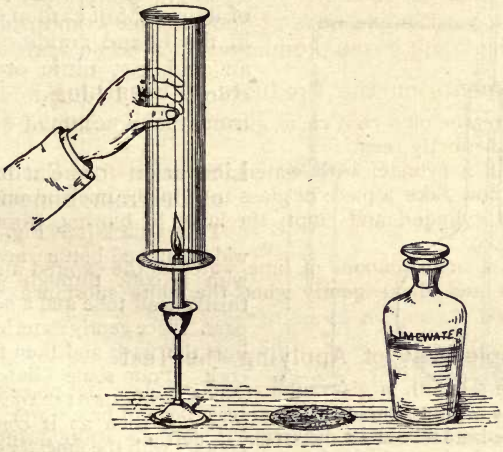

FIG. 10.—Showing the method for collecting the carbon dioxide formed during combustion.

in contact with it, to catch the products of combustion, then add lime water and shake. If convenient the burning body may be put in the cylinder.

If the cylinder is dry it will become visibly misty as soon as it is held over the burning body; this shows that moisture, or water vapour, is also produced during combustion.

Experiment.

Establish by collecting coal gas in a dry cylinder, holding it as in Fig. 10, the absence or presence of carbonic acid in unburnt gas by the above test.

Coal gas contains no moisture, but it may contain some carbon dioxide.

The foregoing experiments have dealt with carbon dioxide mixed with air, but the quantities of the former are not very large; there is only 5 per cent of carbon dioxide in expired air. Now if we want to find exactly what carbonic acid can do, it is plain that the gas must be obtained by itself, i.e. free from all other gases, even air. Limestone or marble contains 44 per cent of its weight of carbon dioxide in the bound condition, and an acid, e.g. nitric or hydrochloric, will liberate the gas from the limestone.

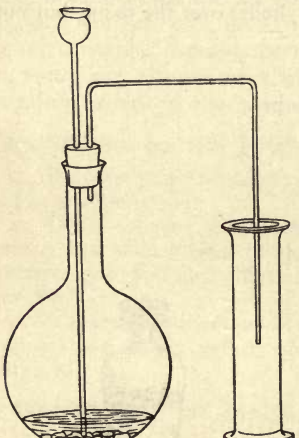

FIG. 11.—Flask fitted with a thistle-head tube and a delivery tube; the latter leads the gas into the cylinder.

Liberation of Carbon Dioxide from Limestone.

Take a flask (see Fig. 11) or a wide-mouthed-bottle, and fit it with a cork through which a thistle-head tube and a bent tube pass. Place gently some limestone into the flask and then fit in the cork. Pour some dilute hydrochloric acid down the thistle-head tube; as soon as it comes into contact with the limestone carbon dioxide is liberated and passes out of the bent tube into the collecting vessel. It is now possible to find what carbon dioxide can do.

Actions of Carbon Dioxide of Importance in Mining.

1. Collect a jar of carbon dioxide by letting the gas flow into it, prove its presence by a lighted taper. A lighted taper held in the mouth of the jar will go out when the jar is full. Pour this jar full into another jar and prove the transference by a light (see Fig. 12).

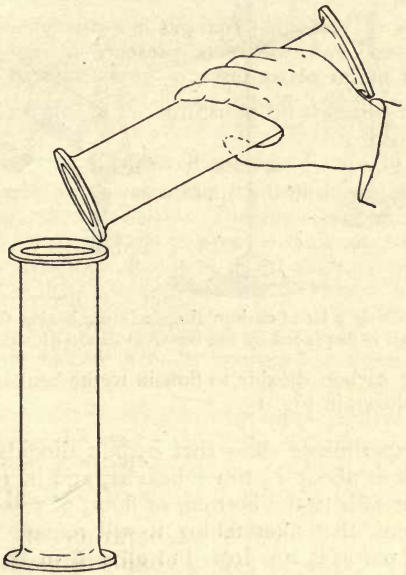

FIG. 12.—Pouring carbon dioxide into a jar full of air; the air is expelled.

2. Fill a jar to the brim with carbon dioxide; prove it is full. Insert a pipette, or tube, into the jar so as to reach the bottom and fill it by sucking up some gas. Find by a lighted taper if there is air at the top of the jar, and carbon dioxide at the bottom.

Some carbon dioxide will have been removed in the pipette and air will go into the jar as the carbon dioxide surface sinks. Imagine the action and the result from your

knowledge of what you would see going on in the jar if filled with water; it is precisely the same action.

3. To show that carbon dioxide is heavier than air counterbalance a dry beaker on one pan of a balance, then disturb it

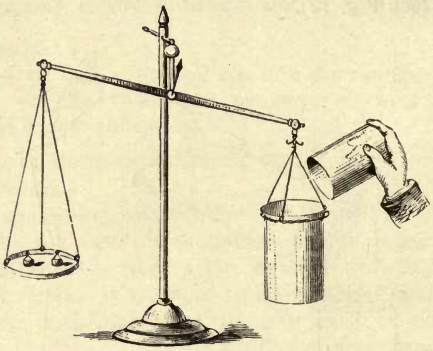

FIG. 13.—Pouring a jar of carbon dioxide into a beaker full of air; the air is displaced by the heavier carbon dioxide.

by allowing carbon dioxide to flow in to the beaker to displace the air, as shown in Fig. 13.

These experiments show that carbon dioxide is heavier than air; it is about $1\frac{1}{2}$ times heavier, and by reason of its heaviness it falls to the bottom, or floor, of vessel, or room. Do not think that after falling it will remain there; as it falls some particles are lost, but all will in time disperse, each individual particle moving away on its own account. If a pond were being stocked with fish a crowd of a few hundred might be thrown in all at once, but each fish would soon begin to move about, and finally they would spread all over the pond. This is what the carbon dioxide particles do; the action is called diffusion.

Gas particles, of whatever nature or kind they are, move about, and so it is impossible to keep gas particles in one place unless it be perfectly closed, i.e. "air or gas tight". This expression tells us that in ordinary life it is recognized that gas particles will escape, but it is not so widely recog-

nized that if some escape others like them or of a different nature go in to take their places.

Experience.

"Keep the bottle tightly corked" is an instruction often given with reference to a liquid in a bottle.

The liquid easily gives off its particles as vapour, and they are usually the essence of the liquid. If the bottle is kept corked they cannot get away and so the liquid keeps its strength. If the bottle is left uncorked then in time all the liquid passes off as vapour, made up of particles of the substance dissolved in the liquid and particles of the liquid itself, and air takes their place in the bottle.

The Diffusion of Carbon Dioxide.

Fill a cylinder with water and then fill one-tenth of it with carbon dioxide, then let in air. This may be done by bringing the cylinder in an inclined position to the surface of the water and then letting the air flow in at a part of the cylinder's mouth held just above the surface of the water. Take a sample of this gas and show, by lime water, it contains carbon dioxide mixed, diffused, or dispersed throughout the cylinder.

The sample may be taken by pouring a small quantity of the gas into a beaker of lime water.

This experiment shows that the layer of carbon dioxide does not remain at one end of the cylinder; the particles disperse or diffuse through the air so becoming uniformly mixed with the air. Compare it with the illustration of fish in a pond.

Extinction of Light by Carbon Dioxide.

Light a candle and pour a cylinder full of carbon dioxide on to it.

Place a small quantity of a combustible liquid in a porcelain crucible (see Fig. 14), ignite the liquid and pour upon it a jar of the gas.

A light, if dependent upon anything undergoing combustion, cannot continue to burn unless it is supplied with air.

Fire Extinguishers.

Carbon dioxide, by its heaviness, its incombustibility, and its power of stopping combustion, is used for extinguishing

fires. It could be used for smothering a lamp in the mine if a store of the gas were kept so as to be poured on to a lamp at any moment. Probably you have heard of a miner's lamp being extinguished by "black-damp" in a mine; this damp contains much carbon dioxide.

There are several methods of storing the gas for fire extinction; one is to force the gas into steel cylinders, and by use of a nozzle and tap a stream of the gas may be played on to a burning body. The gas will become a cloak

FIG. 14.—Extinguishing a burning liquid by using a vessel full of carbon dioxide.

to the fire and so shut off the air from the flames, so the fire is bound to be extinguished.

It is useful in small fires, particularly such as occur in many households, it is most effective if they are on the floor, for the gas is likely to fall by its heaviness.

If the fire were a burning piece of celluloid or any article made of celluloid, of which there are many, even cinematograph films, carbon dioxide would be quite useless for its extinction. We shall find why later on in the book; water would be the only extinguishing agent.

A Few General Matters.

There are different amounts of carbon dioxide in town and country air; in town air it may be as much as 6 cubic

feet of carbon dioxide in 10,000 cubic feet of air, but in country air there is only half this quantity in 10,000 cubic feet of air. These figures stated as percentages will give :—

Town air, ·06 per cent of carbon dioxide.
Country air, ·03 „ „

Town and country air are always trying to become equal in their amounts of carbon dioxide, but cannot do so owing to the large quantities of the latter gas produced in towns.

Expired air, just as it comes from the lungs, contains 5 per cent of carbon dioxide, but the carbon dioxide does not remain in this air after expiration, it immediately diffuses into the air around the human being. It is therefore plain that there must be plenty of fresh air supplied in order that this 5 per cent may be so diluted with fresh air that it becomes practically free from carbon dioxide. The production of carbon dioxide in mines by men and animals, also in small quantities by combustion, and sometimes its supply from old workings, leads to the necessity for a constant stream of fresh air passing through the mine by way of the downcast shaft.

The following table shows the average composition of the air as it passes into the downcast shaft of the mine :—

Oxygen . . .	20·65 per cent.
Nitrogen . . .	77·11 „
Argon . . .	·80 „
Carbon dioxide . .	·03 „
Water vapour . .	1·41 „

The air as it leaves the upcast shaft will not have the same composition. Beyond the carbon dioxide and water vapour produced by combustion and respiration there will be gases given off by explosives, by underground or gob fires, and fire-damp escaping from the rocks and coal face. All these gases will mix with the ventilating current of air as it passes along the airways and so find their way to the upcast shaft and out of the mine.

It is plain from the table that the air is a mixture of gases, and in the mixture nitrogen predominates. Many of the gases known as fire damp, black damp, etc., are mixtures

of different gases with one predominating constituent. These gases we shall have to study; some of them differ from the gases of the atmosphere in being combustible, and therein lies their great danger.

Practical Application to Mining.

The benefit of the improved combustion obtained by placing a chimney over the light is strikingly shown in Hailwood's Combustion Safety Lamp which is illustrated below. The addition of the chimney and internal glass has increased

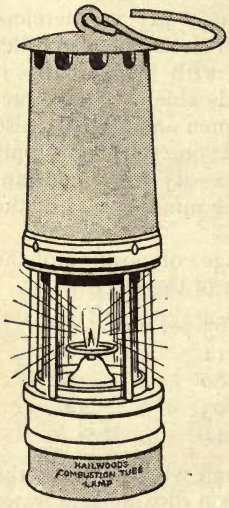

FIG. 15.—Hailwood's combustion lamp.

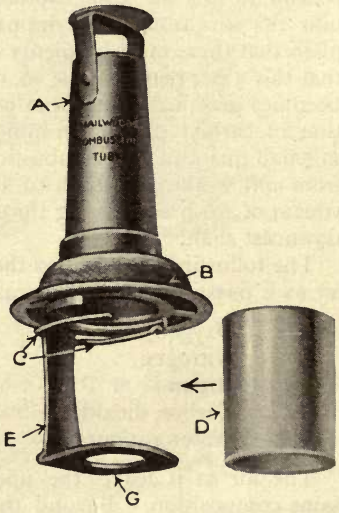

FIG. 16.—Photograph showing chimney, A, and internal glass, D.

the lighting power of the lamp from one-half to about one and a half candle power. This is a very important improvement in view of the fact that miners' nystagmus, which is said to arise from eye strain caused by insufficient light, is rapidly on the increase.

It has already been pointed out that when a safety lamp becomes filled with burning gas, i.e. when gas fires in the

lamp, it should be smothered out by closing up all the air holes by means of which air enters the lamp. It is not generally known among young students that some lamps possess *two* air inlets, the usual one at the bottom of the bonnet and another one lower down. A sketch of such a lamp is given showing the air inlets and the direction of the air currents. When smothering out such a lamp care should be taken to cover up *both* the inlets.

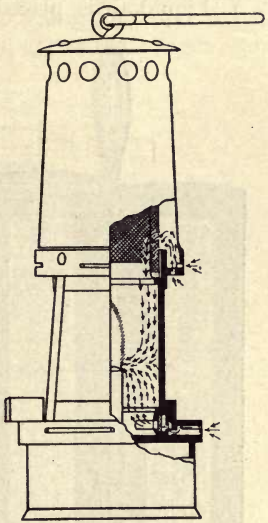

FIG. 17.—Sketch of lamp with two air inlets.

Reference has been made to the hygrometer, and the accompanying illustration (Fig. 18) shows a portable instrument for use in mines.

With the ordinary type of hygrometer, or wet and dry bulb thermometer, the bulbs must be placed some distance apart causing the instrument to be rather bulky. A new form of hygrometer designed for mining work is the psychrometer (Fig. 19) in which the thermometers are placed close together. By means of a handle fitted to a spindle attached to the framework the instrument may be rotated, bringing the thermometers into better contact with the air and giving a quicker reading.

Respiration and the Portable Breathing or Rescue Apparatus.

In exploring a mine after an explosion or in fighting a mine fire the advantage of an apparatus which enables the wearer to breathe fresh air and to be independent of the mine atmosphere will be readily seen.

The types of breathing apparatus in use may be divided into three classes :—

1. The air from the lungs passes into a receptacle con-

taining certain substances which are attacked by the expired air causing oxygen to be liberated. This oxygen is breathed by the wearer of the apparatus.

2. Liquid air is placed in a box or pack carried on the

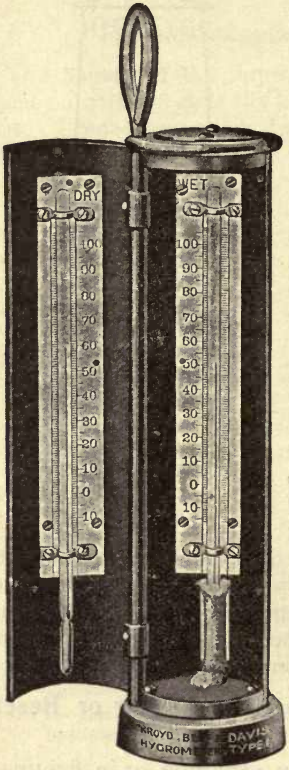

FIG. 18.—Photograph of pit hygrometer.

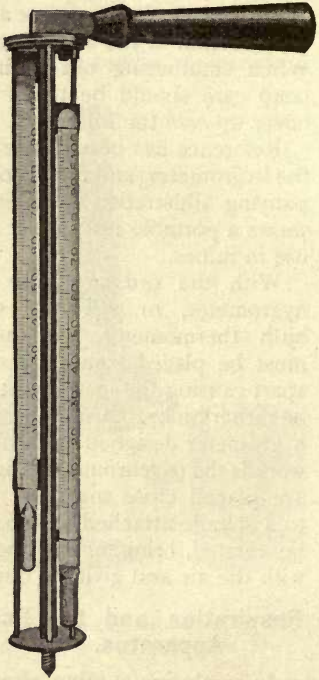

FIG. 19.—Photograph of psychrometer.

back of the wearer of the apparatus. The heat of the body causes the liquid air to evaporate and it is then breathed in the ordinary way. A sufficient supply to last for two or three hours may easily be carried.

3. The carbon-dioxide expired from the lungs is absorbed by caustic soda or caustic potash carried in a suitable case or box. The air, which is now pure but lacking in oxygen, passes on to be breathed again, but before reaching the mouth of the wearer of the apparatus, oxygen from

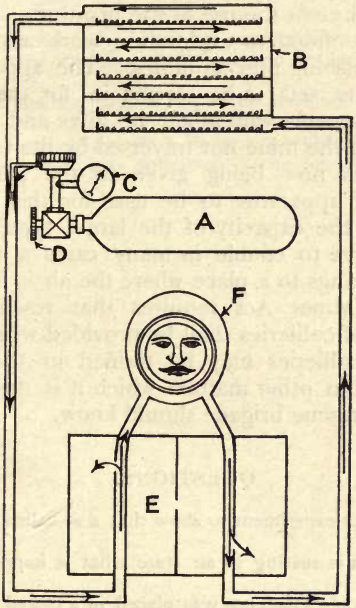

FIG. 20.—Diagram of portable breathing or rescue apparatus: compressed oxygen type.

A, Oxygen cylinder; B, Caustic soda chamber; C, Indicator; D, Oxygen regulating tap; E, Breathing bag; F, Headpiece or helmet.

a cylinder carried on the back is added, making the air quite fit and safe to breathe.

In all types of breathing apparatus it is necessary to have (1) Some means of covering the nose and mouth so that the outside atmosphere may not be breathed. (2) A

breathing bag to enable the wearer to inspire or expire a full breath and to properly empty or fill his lungs.

This bag is usually divided into two parts.

It is also desirable that an indicator should be provided by means of which the wearer of the apparatus is able to measure his supply of oxygen from time to time.

Up to the present the use of the breathing apparatus has been chiefly confined to exploration work after explosions and to extinguishing fires in mines. The apparatus is too heavy for spare sets to be carried in for the purpose of bringing out persons who might be alive and uninjured in the working of the mine not traversed by the explosion.

Attention is now being given to the perfecting of a lighter type of apparatus to be used for this purpose. It will not have the capacity of the larger type, but will be sufficiently large to enable in many cases a man to walk from the workings to a place where the air is fit to breathe.

The Coal Mines Act requires that rescue stations to serve groups of collieries shall be provided where men from the various collieries may be trained in the use of the apparatus and in other matters which it is desirable that a member of a rescue brigade should know.

QUESTIONS.

1. Describe an experiment to show that a so-called empty vessel is not empty.

2. When iron is rusting in air state what is happening to (1) the air, (2) the iron.

3. A combustible substance was placed in a closed vessel containing air and then heated. Will there be any change in the weight of (1) the air in the vessel, (2) the whole apparatus?

4. How could you prove that the gas liberated by heating oxide of mercury is identical with the oxygen of the air? Does the oxygen of the air require liberating from any substance?

5. Three oxide of mercury samples made in different countries were found to contain mercury and oxygen in the proportions by weight of 100 to 8 respectively. Do you think there is anything remarkable in this substance always having its constituents in the same proportions? Give reasons for your conclusions.

6. How could you arrange an experiment to show that the air is concerned in burning and breathing?

7. Compare the properties of nitrogen with the properties of oxygen. What remarkable properties does phosphorus possess?

8. Give three simple and successful methods of smothering a small outbreak of fire.

9. Draw up a list of metals on which air has no action at its ordinary temperature. Mention two substances upon which air quickly acts.

10. Give a short account of the scientific work of Lavoisier.

11. A human being gives out carbon dioxide gas. Prove this statement by experiment and say what is its origin in the body.

12. A saucer of water is placed in the air and it is found on a particular day that no water is lost by evaporation. Would there be any difference in the readings of the wet and dry bulb thermometers on this day?

13. Consider the wet and dry bulb temperatures given on p. 28, then explain why the readings of the intake and return airs differ.

14. A hygrometer hangs in a bathroom which is full of water vapour. Will there be any difference in the readings of the thermometers?

CHAPTER III.

AIR CURRENTS AND HOW THEY ARE CAUSED.

It has been shown that the air of a room or a mine has moisture and carbonic acid added to it by the presence in it of human beings, animals, and burning gas, oil, or candle. For the purposes of health these added substances must be cleared out of mine or room. To bring about this result advantage is taken of air movements, as free as possible from objectionable characters such as a too high speed or too big a rush, so as not to produce winds and draughts. The fire is a means of creating air movement in a room.

Experiment.

Take a lighted match, or a candle, and move it up from the fire to the top of the fire grate; notice the great pull on the light as the highest part of the grate opening is reached; it may be sufficient to blow out the light.

Use a smouldering piece of paper which is giving off smoke, and with door and windows closed see if the following currents are present in a room.

In the room near the fire (F) find the current of air which will draw the smoke of the paper along with it.

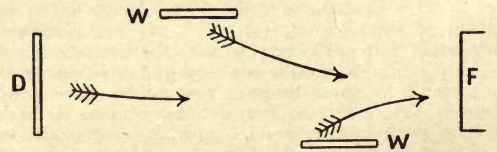

Fig. 21.—Method of mapping the air currents.

At the windows (W) the smoke may be carried away from them, and also on the floor at the door (D); the keyhole of the door should be tried for a current passing through it.

A diagram of the room showing the position of doors and windows should be made, and the arrows put in the diagram according to the direction of the currents. It is possible that the direction of the currents may differ from those given in the diagram; in any case the results of an experiment must be recorded as found.

Experiment.

Slightly open a door which leads from a room into a passage. The door must only be slightly ajar. Find the direction of the air currents at the top and bottom of the doorway by using a lighted match or candle. If the door fits badly then the direction of the currents may be found in the two positions with it closed. The room and passage will no doubt vary in temperature; their temperatures should be taken so as to make the experiment complete.

In a particular classroom it was found by experiment that the bottom of the doorway was an inlet for cold air and the top an outlet for the air of the room. The ceiling of this room was 2 feet higher than its doorway; the room had a temperature of 65° F. and the passage 54° F.

The explanation of these currents of air passing through the room is based upon the fact that air gets lighter as it is heated and is then pushed along by the heavier air behind it, which in its turn gets heated and so is pushed forward. There is thus a continuous flow of air, i.e. a current from the outside, where the air is fresh or pure, to the inside where it gets charged with more or less moisture and carbonic acid.

Heated air also rises by the same cause, and consequently is generally found towards the ceiling of the room.

Experiment.

Take a sand tray and place some sand on it; fix it on a tripod and put it over a Bunsen burner, but have the flame turned low so that it is entirely under the tray. When the tray gets hot a quivering of the air can be seen above it; it is hot air rising. Smouldering paper giving off smoke will visibly prove the rising of the air.

If a thermometer be held well above the tray it will show a rise of temperature, but if it is held at the same distance to the side of the flame there will be little, if any, rise of temperature.

The rising of air on heating may be shown by experiment, for this the temperatures of a room at different heights should be found.

Experiment.

Take a Fahrenheit thermometer and fix it upright on the floor of the room away from any source of heat. Read its temperature.

Repeat the experiment with the thermometer about 6 feet above the floor, and then near the ceiling.

The room is supposed to be lighted by gas and all doors and windows closed.

In each case the thermometer must be given two or three minutes to attain the temperature around the position stated; it should not be touched on the bulb by the hand of the experimenter.

See if your readings warrant you in saying that the greater the height of the position of the thermometer the higher the temperature of the air.

The explanation of the results again depends upon the air becoming lighter as its temperature increases; this lighter and hotter air is pushed up to the ceiling of the room. This rising is not due to the tendency of heat to rise but to the effect of heat upon air; heat increases the air's volume and it therefore decreases the weight per cubic foot. A cubic foot of air at the freezing-point of water has a weight of ·08 lb.; if it were heated to $2\frac{3}{4}$ times the temperature of boiling water it would become 2 cubic feet, and therefore its weight per cubic foot ·04 lb.

In gases and liquids the lighter substance, or the lighter part of the substance, will always be on the top, e.g. oil and water; air and water; hot water and cold water as in the hot-water cylinder.

A Preliminary Inquiry.

Take a vessel called a graduated cylinder; so called from the graduations or divisions on the vessel (see Fig. 22). Compare it with a cylinder not graduated, and note its advantages for measuring a quantity of water or other liquid. If the graduated cylinder is numbered like the one in Fig. 22, then it is called a 100

c.c. cylinder; the symbols c.c. stand for cubic centimetres. The amount of water lying between any two neighbouring graduations is 1 c.c.

If the 100 c.c. of water were weighed it would be found to weigh 100 grams; therefore 1 c.c. of water weighs 1 gram.

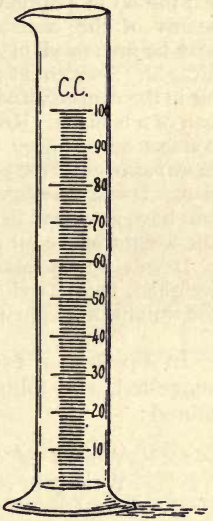

FIG. 22.

The simplicity of the French system of weights and measures is evident from this cylinder, inasmuch as either a *weight* or a *volume* of any liquid may be got by its use if we know the weight of 1 c.c. of the liquid.

Suppose you had a vessel given you exactly the size of Fig. 22, then it would hold up to the top graduation almost 4 c.c. of water. This gives you an idea of the volume represented by the statement "4 c.c.".

Air and its Weight.

A previous paragraph has spoken of the weight of the air; it is important that a simple experiment for obtaining its weight at the temperature of the room should be performed. As air is not very heavy it will be an advantage to state the weight in grammes; 1 grm. is the unit of weight in the French system. The volume must therefore be stated in cubic centimetres; 1 c.c. is the unit of volume. As air expands on being heated a stated volume must get lighter if heated.

One thousand c.c. of air weigh 1·293 grm. at the freezing-point of water, but if it is increased to a volume of 2000 c.c. then 1000 will weigh ·6465 grm.; this would happen if it were heated to $2\frac{3}{4}$ times the temperature of boiling water. As the temperature of the room in which you work is a little higher than the freezing-point of water, the weight you obtain should not differ much from 1·293 grm. per 1000 c.c.

To Show Air has Weight.

Prepare a cylindrical tin vessel (a canister will be found suitable), $4\frac{1}{2}$ or 5 inches long by 3 inches diameter, by boring a

hole in the lid and soldering in an ordinary bicycle tyre valve. Fit the lid in position, carefully solder it on, and see that the seams of the canister are perfectly airtight. The canister may be immersed in water, after pumping in air, to see if it is airtight. Slacken off the valve, to ensure that there is no excess of air in the canister, and carefully balance the dry apparatus on the pan of a balance. Remove the canister, tighten up the valve and connect an ordinary cycle tyre pump. Give eight to ten (or more) strokes of the pump and replace the canister on the scale pan. It will no longer be balanced by the original weights but will have increased in weight due to the additional air ; ascertain the weight of the air pumped into the canister.

It will be necessary to have the canister dry and carefully weighed, before and after the pumping in of air, if we are to find the weight of a volume of air.

In a particular experiment with a tin canister fitted up as suggested, the following weighings in grammes were obtained :—

Weight of canister after pumping	87·33
Weight of canister before pumping	87·05
Weight of air added	·28 grm.

To Find the Weight of 1000 c.c. of Air.

To ascertain the volume of the air pumped in fill a trough (or other suitable vessel) with water. Fill with water, and invert in the trough (as for gas collecting) a glass vessel large enough to receive the volume of air which has been pumped into the canister. Hold the valve beneath the surface of the water under the mouth of the collecting vessel, slacken off slowly so as to allow all the added air to be collected. Measure the volume, and from the figures calculate the weight in this manner :—

To find the volume of the ·28 grm. of air it was collected as described above and a gum label placed on the outside of the collecting vessel level with the surface of contact of water and air. The remaining water was emptied out and then water poured in as far as the gum label. This water was then measured by using a 100 c.c. cylinder.

The following result was obtained:—

Cubic centimetres of air, 218.

The weight of 1 c.c. will be $\frac{\cdot 28}{218}$ and this multiplied by 1000 will be the weight of 1000 c.c.—1·28 grm.

Further Study of Air Currents.

In these experiments on the movement of air by its being heated some difficulty will have been experienced in following the movements on account of the invisibility of the air; flame and smoke have been used to detect its movements. One experiment given on p. 45 dispenses with flame and smoke, and uses the fact that heated air flickers; this is often erroneously stated to be "heat rising". This phenomenon of flickering forms in one way or another very common experience.

Experience.

In a large hall, church, etc., get a position with the light from a window in line with your view of the gas fittings; if the gas is lit for warming, currents of air will be seen rising from the burners.

On a hot day look along a railroad and heated air will be seen rising from it.

Notice the chimney of a foundry when no flame is seen, hot air along with other gases often will be seen rising out of it.

These currents conveying heat may easily be seen in water or other liquids, and an experiment with water will help us to realize what goes on in a gas (see p. 97).

Experiment.

Fix a U tube by a clamp to a retort stand. Make the tube by bending a piece of glass tubing (see following paragraph). When cool three-fourths fill it with water. Warm the U tube at the right-hand bend, but do not let the flame touch the glass. The rising of a heated water current may be shown by dropping into the tube a crystal of permanganate of potash just after warming the bend.

Cutting and Bending a Piece of Glass Tubing.

Glass tube may be cut by making a file mark on it, and then breaking it back at the mark in the same manner as a stick or pencil could be broken in two parts at a mark.

Take a burner of the type shown in Fig. 23, and a piece

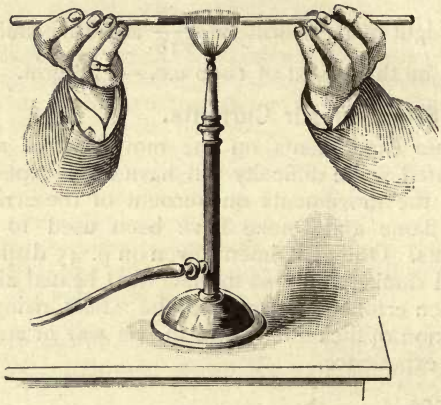

FIG. 23.

of glass tubing 12 inches long.

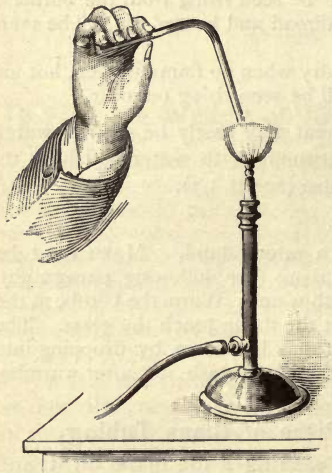

FIG. 24.

Place the tubing about 5 inches from one end in the yellow part of the flame; hold it as shown in Fig. 23 and turn it round so as to soften the glass equally. When the tubing begins to soften control its bending until it has bent through a right angle as shown in Fig. 24. Now repeat the operation at 5 inches from the other end. A tube shaped like the letter U will be obtained; its sharp edges may be rounded off by heating them as shown in Fig. 24.

We have found that when air is heated it rises up and carries the heat with it. Later on it will be shown

by experiment that this heating of air makes it expand and become lighter; the rising up is due to its being pushed up by the heavier and less heated air. It should be noticed that the chimney flue of an ordinary room is an updraught shaft, the lighter air being forced up by the flowing in of heavier air from the room and house.

Mines have been ventilated by having a furnace at the bottom of the upcast shaft (see Fig. 25). The fire causes

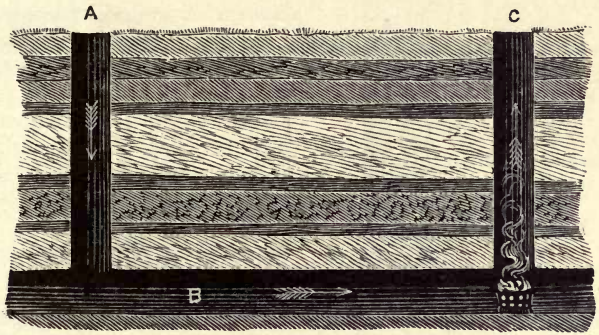

FIG. 25.—Illustrating mine ventilation by furnace: A, C, are the shafts; B, the main airway.

the air in the shaft C to become lighter, and heavier air falling down the shaft A pushes it along and takes its place. The air passing down the shaft A is guided into various parts of the mine before it reaches the upcast shaft.

Furnaces are not now largely used for ventilating mines, but the dimensions of one in actual use should be interesting, it is situated near the bottom of the upcast shaft. These dimensions are: length of furnace 60 feet, breadth 11 feet.

To produce an updraught and downdraught the following experiment should be made:—

Experiment.

Take a large flask and fill with smoke by charring some paper inside. Cork it loosely and let the flask cool; it will lose no smoke, then after removing the cork and fitting a piece of cardboard into the mouth of the flask, as a partition, place under it a

small flame. A current of air will pass into the flask and sweep out the smoke. See Fig. 26, A, B, for the shape of the partition.

The following experiment shows another way of producing draughts :—

Experiment.

A lamp glass is fitted with a piece of cardboard A, B, cut in the shape of a T. The base of the lamp glass stands on a piece

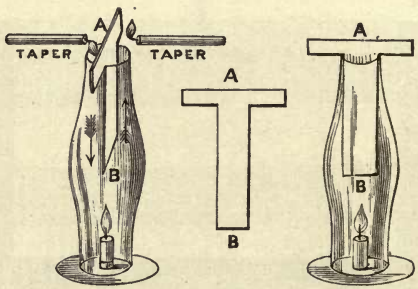

FIG. 26.—Showing an arrangement for experimentally producing upcast and downcast currents.

of cardboard, or wood, and carries a short piece of candle. In finally fixing the glass over the lighted candle keep it slightly to one side of the T partition. Show by using a lighted match or taper (see Fig. 26) that up and down currents are produced.

Look around the classroom and see if there is a long rectangular box on the wall, called Tobin's tube, see Fig. 27. There may be one let into the wall with an iron flap which opens into the room; if there is perform the following experiment :—

Experiment.

Hold a light at the top of the tube and notice if there is a current of air deflecting the light—it should be deflected away from the wall on account of the tube being an upcast shaft.

Wherever air is flowing, no matter how the flow is produced, it is moving to a place where its weight per cubic

foot is less. As soon as any two parts of the atmosphere have different weights per cubic foot a draught or wind is produced. When there is no draught or wind the weight per cubic foot of the air is the same everywhere. Weight makes a substance, exerts pressure, therefore read the foregoing sentences through using the word "pressure" instead of the phrase "weight per cubic foot". It is easily concluded that the heavier cubic foot of air must exert the greater pressure on account of its greater weight.

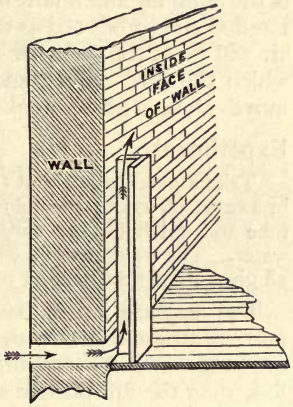

FIG. 27.—Tobin's tube.

Experience.

A strong wind blowing across a chimney-pot improves the draught of the chimney, see Fig. 28. This is due to the aspirating force of the wind which creates less pressure in the flue by clearing out some air and so more air rushes up the chimney.

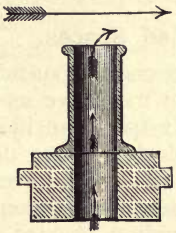

FIG. 28.

It is important to notice that light air is often spoken of as rarefied air, or less dense air; the idea is just the opposite to that which is meant by compressed air or more dense air. The method of heating air so as to make it lighter, so starting its flow, has been applied to mines, but is now replaced by the use of a large wheel called a ventilating fan. This fan is situate at, or near to, the top of the upcast shaft; it acts by lightening or rarefying the air of the upcast shaft. The action of the fan should be easily understood, because we have learnt by fanning our face that a draught can be produced by movement. Every boy knows that if he wafts a card before a fire he will draw the smoke of the fire towards

him; the action starts a draught in opposition to the updraught of the chimney and finally overcomes it. A space containing rarefied air is produced as the card moves along; the rarefied air will be at the back of the card, i.e. in the place from which the card moves, and into this space the heavier air moves along with its smoke.

Experiment.

Take a glass tube about 1 foot long and a ¼" diam. and place it in a vessel of water; then blow strongly across the open end of the tube and watch for any variation in the height of the column of water. The water may be coloured to see its movements. Fig. 28 gives the corresponding natural action.

The explanation is based on the sweeping out by the current of some air in the tube and the pressure or weight of the air on the water surface in the tube becoming slightly less, than the full outside air pressure drives up, slightly, the water column.

Experiment on Disturbances of Air.

Open or close a door quickly, leaving plenty of time between each action, and find the direction in which a candle flame is moved by the opening and closing.

Rarefied Spaces.

If we consider such fast-moving things as tram-cars, motor-cars, or trains, we may recall to mind that when moving at a great speed we have seen paper and dust lifted up and carried along for a distance. This is due to a disturbance of the air; as the travelling body changes its position quickly it leaves a space containing rarefied air, and into this the surrounding heavier air rushes. It is said the paper is sucked along by the train or car, whereas really it is swept forward by the onrushing heavier air finding its way towards the rarefied air space and filling it completely.

Some cyclists maintain that it is easier to ride when behind a motor-car on account of getting into the "suck" of it, which really means that you get at your back the air rushing in to fill the place vacated by the car, and so you are helped. It is practically a wind at your back. It is important, therefore, to remember that the air may be rarefied

not only by heating it but by a body passing through it at a big speed. If a wheel carrying vanes on its outer rim could be kept revolving at a big speed it would throw the air away from it, and the surrounding air by its greater pressure would flow towards the wheel again in its turn to be hurled away.

Illustration.

Imagine a big crowd of people standing at the gates of a football ground and then the gates are opened. The people scatter in all directions after passing in, that is, the crowd becomes rarefied, their places are taken by other parts of the crowd and these in their turn spread out. The pushing, or pressure, of the crowd and the scattered parts are totally different : the pressure at the gates is the greatest and just inside it is the least. In this way the crowd by its pressure moves to where the pressure is less. It is so with air particles filling up a rarefied space : a huge crowd by their pressure rushes the few in the rarefied space away and then occupy it.

Practical Application to Mining.

Ventilation in mines is necessary to renew the air used up in the process of breathing, but there are other things, such as the high temperature of the rock in deep mines, the burning of lamps, the fumes and smoke from explosives, and the noxious and inflammable gases given off from the coal and surrounding rocks, which make it essential that adequate ventilation should be provided.

Various means of producing ventilation in mines have been employed in the past. The furnace, the water-fall, the steam jet, and the displacement machine—similar in principle to the ordinary water pump—have all been used, but have now given place to the fan in a great majority of cases.

In recent years great alterations have taken place in the design of mine fans, and to-day instead of large and heavy fans—30 to 50 feet in diameter—requiring expensive foundations and large engines, smaller fans running at higher speeds are used.

Formerly the blades of fans extended from the centre to the circumference and were straight or curved backwards in the opposite direction to that of rotation.

Now the tendency is to make the blades very short leav-

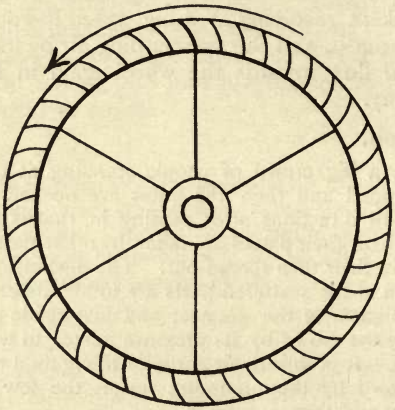

FIG. 29.—Fan with short blades curved forwards.

ing the centre of the fan clear, and they are often curved forward in the direction of rotation of the fan.

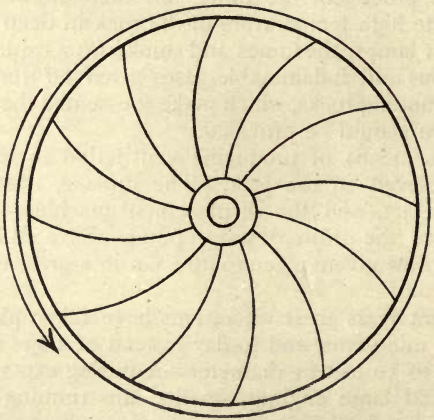

FIG. 30.—Fan with long blades curved backwards.

In order to efficiently ventilate a large modern mine

enormous volumes of air are required, and very powerful engines are necessary to drive the fan. A quantity of 300,000 cubic feet per minute is not unusual, and assuming a cubic foot of air to weigh $1\frac{1}{4}$ oz. we find that about 10 tons of air goes down the pit every minute, or about 15,000 tons every twenty-four hours. The reason why such powerful engines are required to drive the fan is that the air in

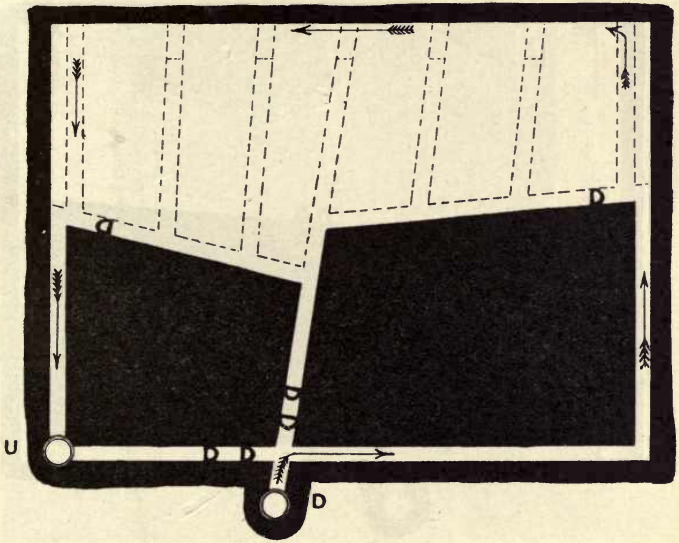

FIG. 31.—Plan showing method of ventilating a mine by a continuous current of air.

D, U, Downcast and upcast shafts. D, Doors in roadways.

passing through the roadways meets with so much resistance from the roof, sides, and floor. The smaller the airway the greater is this resistance, so that for efficient and economical ventilation large airways, as square in section as possible, are advisable.

In the early days of mining it was the custom to send the air round the mine in one long continuous current, but now it is split up into a number of shorter currents each ventilating a separate district. In this way the men get fresher air;

an outburst of gas in one district does not necessarily foul the air in another district; the quantity of air going into the mine is increased and the ventilation is more efficient in every way. In order to make the air travel in the path decided upon and to ensure that each district shall receive its proper share of the ventilation, air crossings, doors, sheets, and regulators are necessary.

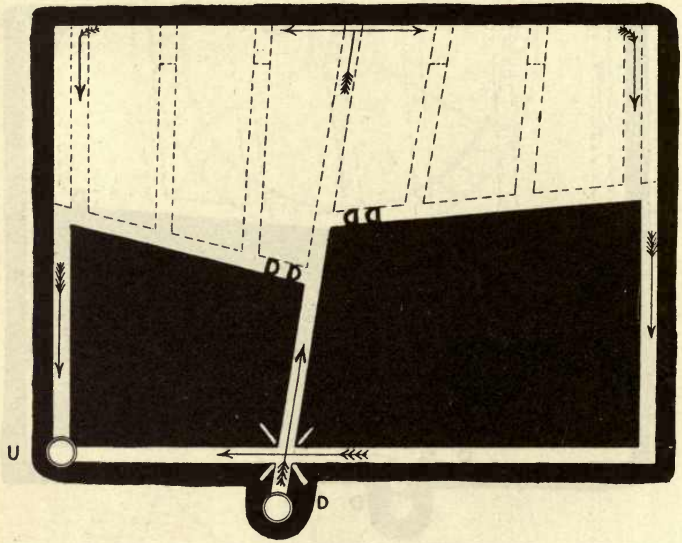

FIG. 32.—Plan showing method of splitting the air current. D, U, Downcast and upcast shafts. D, Doors in roadways.

In some cases an airway carrying air from the workings is required to pass over or under an airway carrying fresh air to the workings, the angle of crossing being approximately at right angles. The crossing may be effected by driving a tunnel or stone drift in the solid rock over the road to be crossed, or roof may be taken down and an air crossing of brickwork, girders, and concrete, or brickwork and timber, erected.

Doors are used for guiding the air into its proper path and to prevent it taking a short cut back to the upcast

shaft. They are made of wood and hang on a wooden frame fixed in the roadway, the spaces between the frame and the sides of the roadway being filled in with bricks and mortar.

Sheets or canvas doors are used for the same purpose as

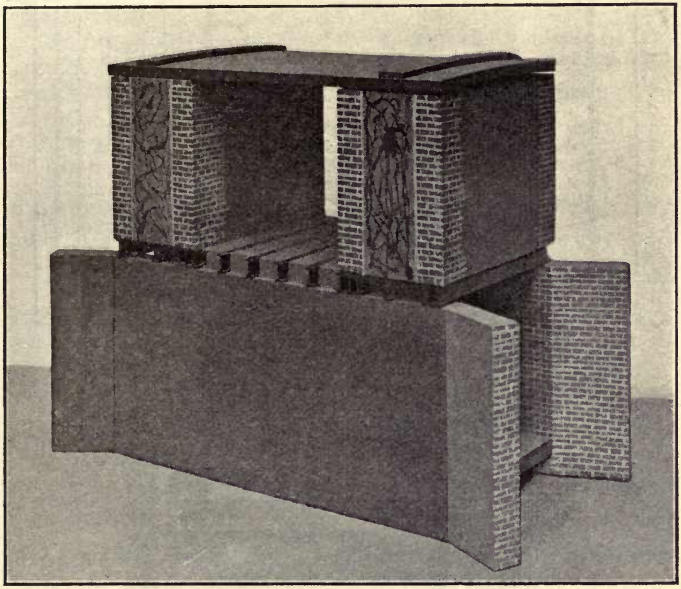

FIG. 33.—Photograph of model of an air-crossing. Girders are placed across brick walls the space between them being filled in with concrete. Double brick walls are built on the girders and the spaces between them filled in with stone packing.

doors in less important positions. They are often made of a kind of tarred canvas called brattice cloth and hung from suitable supports near the roof.

At Leycett Colliery in North Staffordshire sheets of leather are used. The leather is fastened with a clip made of two strips of wood which is attached to a strong lath by means of a number of hinges; this lath, fastened near the

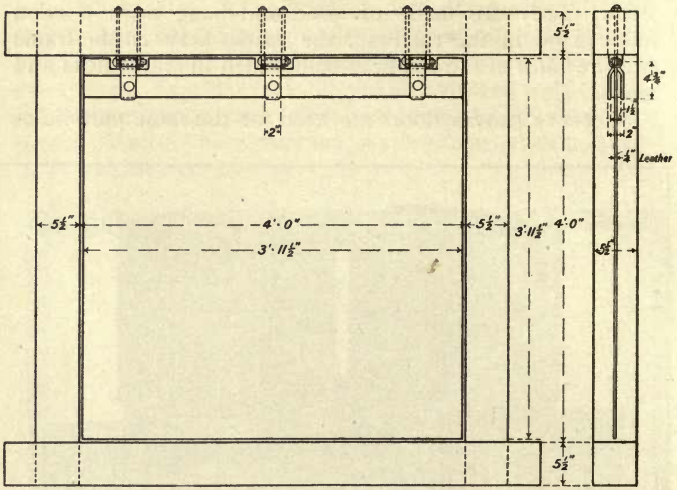

FIG. 34.—Drawing giving particulars of leather ventilating sheet.

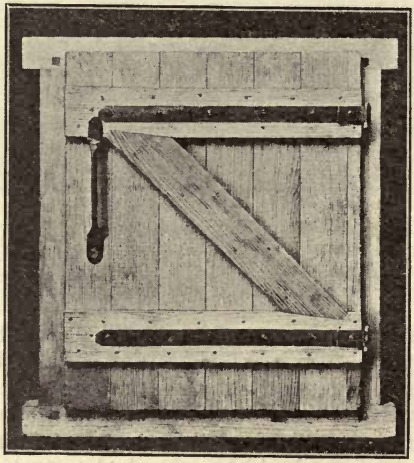

FIG. 35.—Photograph of ventilation door.

roof, supports the sheet. The leather being much stronger than canvas does not wear away so quickly, and it also answers better the purpose for which it is intended.

When the various districts into which the air is split are unequal in length, the shorter splits would get more than their proper share of air unless means were adopted to prevent this.

The regulator by reducing the area of the roadway in the shorter splits regulates the quantity of air passing in the various splits and ensures the proper quantity going into each.

When the use of roadways connecting the intake and

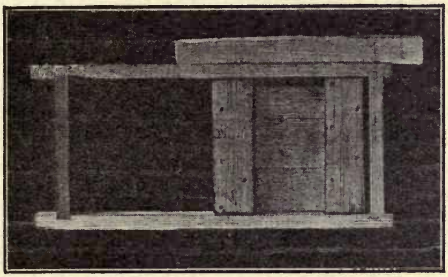

FIG. 36.—Photograph of regulator (door closed).

return airways of a mine is discontinued, these roadways must be sealed up by stoppings which should be built to specifications laid down in Regulations under the Coal Mines Act.

It is often necessary to drive headings or roadways into the solid coal. These are usually driven in pairs and are connected at intervals by cross roads or slits. Ventilation is carried to the face of these headings usually by means of brattice cloth or air pipes (see Fig. 37, p. 62, Nos. 1 and 2).

No. 1 shows the method of ventilating a pair of headings under normal working conditions. No. 2 shows method of removing an accumulation of fire-damp from a pair of headings. The stopping at A is taken out and brattice cloth erected as

shown by dotted lines, removing the gas in layers or slices until B is reached. The stopping B is then taken out and a

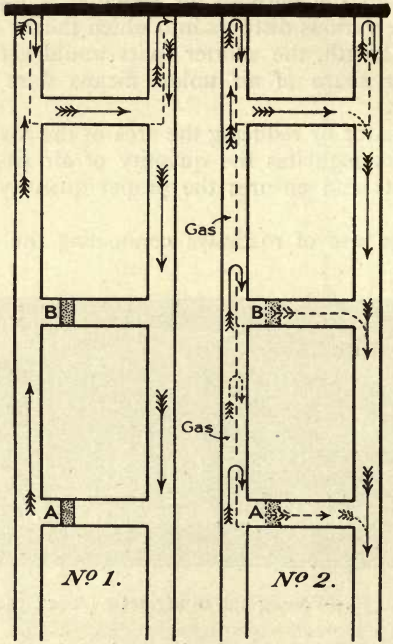

FIG. 37.—Showing method of ventilating headings and method of removing fire-damp.

similar method of procedure adopted until the whole of the headings are clear of gas.

It is very important that the quantity of air passing into the various districts of a mine should be known. Quantity in the case of mine air is usually expressed in cubic feet per minute, and the product of the speed in feet per minute and the area of the roadway in square feet will give this result.

The speed of the air current may be obtained by causing smoke or dust to travel in the air and then measuring the

time taken for this smoke or dust to travel a measured distance.

Example: Smoke travels 25 yards in 13 seconds, find speed in feet per minute.

$$25 \text{ yards} = 75 \text{ feet.}$$

$$\frac{75}{13} = \text{feet travelled in 1 second}$$

$$\frac{75 \times 60}{13} = \text{feet travelled in 1 minute}$$

$$= 346 \text{ feet per minute (approx.).}$$

The smoke necessary for measuring the speed of the air current may be made by lighting a very small quantity of gunpowder or a piece of powder fuse, but this method is only suitable for mines where inflammable gas is unknown and which are worked by naked lights. In gassy mines the fumes formed by bringing together ammonia and hydrochloric acid might be used, and a rough measurement could be obtained by throwing a handful of fine dust into the air.

The above method if carefully done is very accurate and very useful for checking purposes, but in practice a special instrument called an anemometer (see Fig. 38) is used. It consists of a number of vanes placed obliquely round an axis. The air blowing into the vanes turns the axis, which motion is communicated by suitable mechanism to dials which register the number of feet of air passing.

To measure the air the reading of the instrument is first taken. It is then held in the airway for a given time, say one minute, and a second reading taken.

The difference in the two readings will then give the speed in feet per minute.

The following extracts from Regulations under the Coal Mines Act, 1911, are very important and should be impressed upon all mine workers:—

"1. If any person shall cause or become aware of any obstruction in or interference with the ventilation he shall if it falls within the scope of his duties to remedy such obstruction, interference, or other source of danger, immediately take the steps necessary for the purpose, and if not he shall immediately inform the manager, under-manager, deputy, or

other official, and shall if he is working at the place where the danger exists cease all work at that place.

"2. No person shall, without authority, pass beyond any fence or danger signal or open any locked door.

"3. Every workman working at the face shall to the best

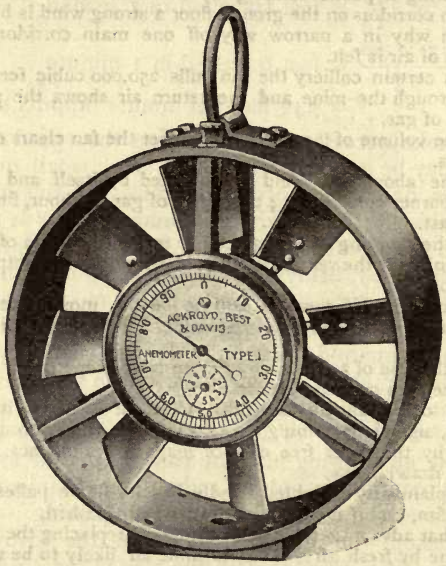

FIG. 38.—Anemometer.

of his power carry on his work so as at all times to leave a free passage for the air current.

"4. Every person having occasion to pass through any door or canvas screen or flap shall carefully close the same."

QUESTIONS.

1. How is the air in underground workings of mines fouled?
2. What dangers are likely to arise from the breathing of impure air? Consult your history book on the story of the Black Hole of Calcutta before answering the question.

3. A large colliery may be circulating 500,000 cubic feet of air per minute. Why should such a large quantity be used?

4. What agency is continually pressing air forward in your mine from the downcast to the upcast shaft?

5. What are the advantages of splitting the intake air into several different currents instead of making it one big current passing through all the working places?

6. Entering a public building by the main door which opens to three main corridors on the ground floor a strong wind is blowing. Explain why in a narrow way off one main corridor very little movement of air is felt.

7. At a certain colliery the fan pulls 250,000 cubic feet of air per minute through the mine and the return air shows the presence of 1 per cent of gas.

Find the volume of "gas" in cubic feet the fan clears out per day of 24 hours.

8. If the above gas could be collected by itself and used in a batswing burner consuming 4 cubic feet of gas per hour, find how long it would last.

9. As the working of coal gives rise to the liberation of much gas, do you think that the ventilation should alter with the output of coal? Give reasons.

10. Ventilation if good is said to be the most important of all things in making for safety in the mine. What does this statement mean?

11. Is the use of a good safety lamp more important to the safety of the mine than good ventilation?

12. An office fan consists of a wheel of 4 vanes, is driven by electricity, and when running draws a current of air through a room. Explain why the lower free ends of maps and almanacs hanging on a wall are drawn away.

13. Explain why a lighted candle has its flame pulled towards a revolving fan, and if brought too near is extinguished.

14. What advantages are to be gained by replacing the atmosphere of the mine by fresh air? Why is mine air likely to be unhealthy if not diluted with fresh air?

15. The standard of purity for mine air is not less than 19 per cent oxygen and not more than $1\frac{1}{4}$ per cent of carbon dioxide. State the differences between these amounts and those found in fresh air. Why should the standard only apply to oxygen and carbon dioxide?

16. Explain how a street lamp, not an electric one, is ventilated, i.e. the manner in which it gets fresh air and gets rid of foul air. Does an electric lamp require ventilation?

17. An individual breathes about 400 cubic feet of air in twenty-four hours. Count the number of breaths you make in a minute (generally it is about eighteen), and then calculate the number of cubic inches of air you take in at each breath.

18. What has the air gained and lost as a result of your breathing it?

19. What is the intake for fresh air in your bedroom, living room, and schoolroom? Is there anything similar to an upcast shaft? Give in each case the return airways.

20. George Stephenson as far back as 1835 said that in order to avoid explosions in mines two shafts should always be sunk. What advantages are there in two shafts for ventilation purposes?

21. Explain why convection currents are produced around every source of heat. Are these currents produced by a filament electric lamp?

22. What is the value of convection currents in ventilating a room? A coal fire requires $3\frac{1}{2}$ times more air for combustion than a gas stove fire. Which do you therefore consider the better for ventilating a room?

23. A watchman's fire, red hot in daylight, showed flickering of the air around it. Explain how this is caused.

24. Consider the arrangement in the Bunsen burner for the intake of air, and then explain how mines might be ventilated by a jet of high-pressure steam. This was actually done for the first time in 1828 at the bottom of the upcast shaft.

25. How can it be proved that air has weight? Will the weight of (1) a cubic foot of air, (2) a particle of air, vary with its temperature?

26. What is a blower? Is the pressure of the gas in a blower greater than that of the air? Make a comparison between the actions of a blower and those in the tin can experiment on the weight of the air.

27. Consider the following fact and then answer the question. A fall of 1 inch in the height of the barometer means a decrease of weight of the air on every square inch of surface in the mine of 2 lb. If there is such a fall in the barometer on any day, is gas in the gob or waste likely to escape more easily?

28. Consider the following figures:—

1000 cubic feet of air at 32° F. weigh 81 lb.
" " " " 110° F. " 70 lb.

If a ventilating fan pulls through a mine 250,000 cubic feet of air per minute, will its weight vary in summer and winter?

29. Can you explain why a cubic foot of air should have a less weight at a high temperature than at a low one?

CHAPTER IV.

THE INCREASE IN SIZE OF SUBSTANCES BY HEAT, AND ITS USEFUL APPLICATIONS.

ALL bodies possess the power of taking up heat, and as it is taken up the heat has several effects upon them; it alters their hotness or temperature; makes them increase their size; it may also make a body change from a solid to a liquid, or even to a vapour.

Experience.

Recall some common facts to show that solids, liquids, and gases take up heat. Water contained in a kettle and put on the fire gets heated. The solid material of the kettle first takes up the heat and then passes it on to the liquid water.

The sun's heat passing into a greenhouse, or in any room with plenty of glass windows, heats the air inside.

The foregoing experience is common to all of us; it might be very much extended. It is sufficient to note, however, that it points out that all kinds of substances, solid, liquid, and gas, will take up heat. It is owing to their temperature having increased that we feel quite sure they have absorbed heat.

Take the second effect caused by absorption of heat, i.e. increase in size; this has to be allowed for in structures made of metal.

Experience.

Gaps, of at least half an inch, are left between the ends of the rails on the railroad; metal bridges are constructed with one end free to move on rollers, e.g. a distance of 6 inches is allowed in the Forth Bridge for its free expansion. Furnace chimneys of brick have iron bands around them to control their expansion. A vessel,

e.g. a saucepan, exactly filled with water will overflow long before it boils. The liquid in the thermometer rises in height as it takes up heat.

As a body loses heat it decreases in size; its decrease in size on cooling will be exactly the same amount as its increase on being heated if it starts at the temperature of the air and finally cools to the same temperature.

Experience.

The wheelwright puts the iron hoop in a red-hot state on the wooden rim of the wheel. Circular iron plates are often seen on outer walls of buildings; these are connected inside by an iron rod running from plate to its opposite plate. The iron rod was screwed up hot and on cooling drew up the leaning walls.

Here we have the shrinkage of the cooling metal exerting a great force which is utilized in tightening the parts of the wheel or pulling in leaning walls.

This passage back of a heated body to its original length, like its expansion, is not a jerky process but a gradual contraction; as the body loses equal small amounts of heat its size decreases by equal small amounts.

Experiment.

The expansion and contraction of any iron structure may be shown by the following experiment (Fig. 39).

An iron bar about 20 inches long is supported on two blocks; one end of the bar is put in contact with a heavy weight. The

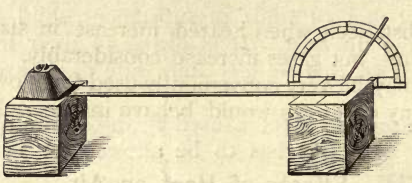

Fig. 39.

other end rests on a big pin, or needle, which is passed tightly through a strip of cardboard as an indicator, the position of this indicator in front of a piece of cardboard, or a protractor, is shown in Fig. 39. Heat the bar strongly by a Bunsen flame.

The expansion of the bar does not push the pin along, the latter acting as a roller tends to turn the indicator

round. In this way the lengthening of the bar on heating is proved. As the bar cools it will contract and the indicator will return to its original position. Compare this arrangement with the practical arrangement of one end of a bridge being placed on rollers to allow for lengthening. This experiment illustrates the plate and bar method for straightening leaning walls; after heating and screwing up the plates, the cooling bar produces an irresistible pull.

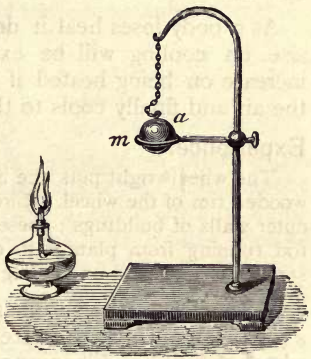

FIG. 40.—Gravesande's ring.

The following experiment, based on using the ball, *a*, and the ring, *m* (see Fig. 40), will illustrate the action of the contracting iron hoop.

Experiment.

Notice that the ball, *a*, will only just pass the ring, *m*, when both are cold; then if the ring is heated the ball will pass through easily, and as the ring cools it contracts and the ball will again only just pass through. The figure shows the ball when it has been heated, and owing to expansion it does not pass through the cool ring.

Solid substances, when heated, increase in size by a very small amount, but gases increase considerably. As the air is a gas it may be very conveniently used for showing expansion, but any other gas would behave in precisely the same way.

Effects of Heat on Air.

Experiment.

Take a small flask and fit (see Fig. 41) its mouth with a cork; through the latter pass a well-fitting glass tube. The tube should project beyond the cork, about ½ inch inside and about 8 inches outside the flask. Invert the apparatus so as to put the tube in a tumbler of water; on warming the flask gently,

e.g. by the hand, bubbles of air pass through the water. Allow

FIG. 41.—Showing air expands by the heat of the hand.

the flask to cool in the position shown in the figure, and observe that water rises up the tube.

An Explanation of the Effects.

The experiment starts with a flask of air which is of the same *density* as the atmosphere, that is, the weight of a cubic inch of air inside the flask is the same as the weight of a cubic inch outside. When the air in the flask is heated it increases in bulk; the bubbles coming out show there is an increase. It follows then that there is after heating less weight of air in the flask, and therefore its density, i.e. its weight per cubic inch, has decreased. As the air in the flask cools it shrinks to its original density, and stops shrinking when, as at the beginning, the inside and outside air is again equal in density.

Heated air, therefore, is lighter than cool air, but it may lose its heat and so come back to its original state. Cool air by its greater weight can push lighter air out of its place.

The meaning of the word density is of some importance and should therefore be grasped. If a liquid, or a solid, or a gas, be heated and it increases in volume its density must get less. Consider the following three substances and their weights per cubic foot :—

Air	·08 lb.
Water	62·50 lb.
Iron	468·75 lb.

When heated they all increase in bulk and so their weight per cubic inch or cubic foot must decrease. This means that there will be fewer particles in a cubic inch or cubic foot, and so the density has decreased. If 1 cubic foot of air had the temperature of ice and were then heated to a temperature $2\frac{3}{4}$ times as great as that of boiling water it would become 2 cubic feet and its weight per cubic foot be ·04 lb. It follows then the particles per cubic foot have been halved in number, and therefore it is said the density has been halved.

Illustration.

The numbers and words on this page are 317 and the size of the page 31·7 sq. inches ; therefore it may be said that their density is 10 per sq. inch. If the numbers and words were halved or doubled the density would be 5 or 20.

The Expansion of some Common Substances.

If the following substances are heated from the temperature of melting ice to the temperature of boiling water, they will increase in size to different extents ; the relative amounts of increase are shown by the following figures :—

Iron	1
Zinc	$2\frac{1}{2}$
Mercury . . .	5
Water	12
Air	100

The table points out the large amount by which air expands compared with iron for the same rise of temperature ; it also points out another general fact, that liquids do not expand as much as gases but more than solids. The table further

shows that solids and liquids differ in their amounts of expansion. The number representing air would do for any other gas, e.g. marsh gas, which means that all gases expand by the same amount for the same increase of temperature.

Experiment.

Strike a match, or light a taper, and notice that whatever be the position of the burning body the flame is directed upwards.

The flame is lifted upwards by two causes: the vapour forming the flame is lighter than air and therefore, like a balloon, tends to rise; again the heat of the flame expands the air and so starts rising currents. The joint effect is to pull the flame upwards.

Measuring Temperature by the Expansion of a Substance.

If a body does not change in temperature we are certain that it is neither gaining nor losing heat, and it will not in such a condition alter in either length, breadth, or thickness. We may regard heat in its action on a body as behaving like a force which by pushing the particles of the body further apart increases its size.

If an iron rod were fixed on the wall of a room it would increase in length as the air of the room became hotter, the increase would be difficult to see, or to show in a simple manner that the rod had increased in length. A solid is therefore not a practicable thing for measuring alterations of temperature by observing its increase of length.

Recall the experiment on p. 68 (Fig. 39), and notice that you were not asked to measure the increase in length of the bar; such a measurement would not have been an easy matter. The bar increases in length by a very small amount and only by special means, or in a special way, can it be measured.

An Experiment Described.

The bar of iron used in this experiment was exactly 20 inches in length; it had been kept in a cupboard whose temperature was 60° F., this was therefore the temperature of the bar. It was

then placed on two pennies, one at either end, resting on the stove of a school-room. On the upper face of the iron was tied, by wire, a thermometer, which in time showed an unaltering temperature of 260° F. An attempt was then made to measure the bar's length by a 2-foot rule but no increase of length could be with certainty detected. By a special way of measuring it was found to have increased $\frac{1}{10}$ of an inch in length.

If in order to measure changes of temperature it were suggested to use a gas shut up in a glass tube, the difficulty due to its having no visible surface, and of its filling the tube, would render it necessary to abandon the idea.

Now a liquid has a surface which can easily be seen, and it may fill the tube in which it is placed to any desired extent. Moreover, the table on p. 71 tells us that liquids expand more than solids, and therefore any increase of height of a liquid in a tube would be more easily seen than the expansion of a metal rod.

Experiment.

Fit up a flask as shown in Fig. 42.

A long fine-bore tube passes through a cork; it must be well fitted so as to prevent water oozing through the joint. Fill the flask completely with water, then when the cork and tube are replaced in the flask water will rise up the tube. Mark its position by a strip of gummed paper. Warm the flask gently by holding it high above a gas burner, and note the effect on the water in the tube. Allow the flask to cool and note what happens in the tube.

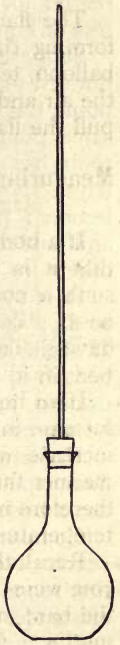

FIG. 42. — Flask fitted ready for filling with water; to show expansion on warming.

The surface of the liquid in the tube may sink as the flask is first warmed; the flask has expanded, and its holding capacity increased, before the water has had a chance to do so. After this the water expands and creeps slowly up the tube, but on cooling sinks to its original level. Similar effects would be obtained with other liquids, e.g. alcohol, turpentine, mercury, etc.

In principle the apparatus is a thermometer, and if its tube were marked in some approved way it might be used for finding temperatures.

It is agreed after considering all the pros and cons that a liquid is the best substance for the purpose of measuring changes of temperature, and the most convenient arrangement is to put the liquid in a fine-bore tube sealed at its upper end and a bulb, or reservoir, at its lower end. The reason for closing the top is to keep out air and prevent loss of liquid.

Suppose that such a tube is placed in a room and it is noticed for several days that the liquid rises from the same point, travels through the same height, and then falls to that same point again. We are sure the temperature in that room has altered by the same amount on those successive days. Names must be selected to denote the two points between which the liquid has travelled, and for simplicity and understanding every one must use these names and no others for these points.

It is therefore necessary to come to some agreement and to fix a starting-point in the measurement of temperature. It seems reasonable to say that when any substance has no heat in it, its temperature should be denoted by nought, o, or zero, just as the amount of water in a dry vessel would be represented by any one of the same statements.

Unfortunately we cannot get a body with no heat, so in fixing the starting-point in measuring temperature we must use a body which, although cold, still possesses some heat.

Compare this difficulty with our method of numbering years. Nothing is known of the beginning of time, i.e. the first second of the first day of the first year of this world's existence, so we make the birth of Christ the starting-point, and count forward to the present year, and backward for preceding years, e.g. it is said the Pyramids were built in Egypt 3633 years B.C., i.e. before the starting-point of the Christian Era.

The Starting-point on the Mercury Tube.

If a tube containing mercury is surrounded by melting ice it will in time come to the temperature of the ice; as it

does so the mercury in the tube will shrink in bulk until it reaches a certain height, and as long as it is kept surrounded by melting ice the mercury will remain at this height. If the height of the mercury remains unaltered, it means that the temperature of the melting ice is always the same. Wherever or whenever melting ice is got, then if a tube were surrounded by it the mercury would always stand at the same height. This is a real starting-point, because the mercury never alters its position; it might be called the melting-ice position. It is, however, spoken of in the two following ways: Nought degrees Centigrade, or thirty-two degrees Fahrenheit, and represented shortly in these two ways: 0° C. and 32° F. In either case it means the same hotness, i.e. the same temperature.

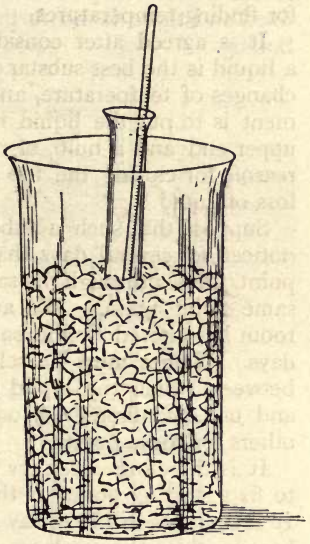

FIG. 43.—A long, fine, closed tube with a bulb on, placed in a test tube and surrounded by melting ice.

Experience.

A scale rule is well known to you, the construction of it for measuring purposes is based upon *two* fixed points. There is one point, or end, represented by 0, called the beginning, and another end marked by a number; between the 0 and the end number there are many equal spaces. If we are considering a foot rule then the end number is 12 and the spaces between are called inches of length and represented by the numbers lying between 0 and 12.

The Second Fixed Point on the Mercury Tube.

The changing of ice into water has given us one fixed point, and it would be very convenient if water turning to

steam had a temperature which is a fixed one. It has been found that when pure water boils its temperature becomes fixed and there is no further change as long as it is freely boiling.

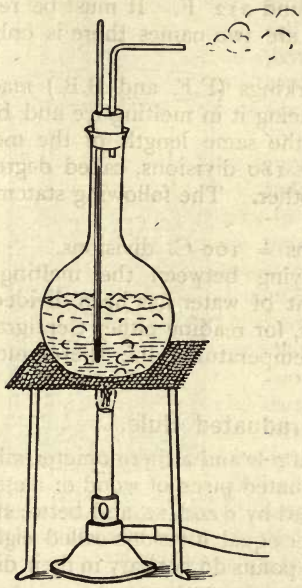

FIG. 44.—The mercury tube fitted through a cork into a flask containing boiling pure water.

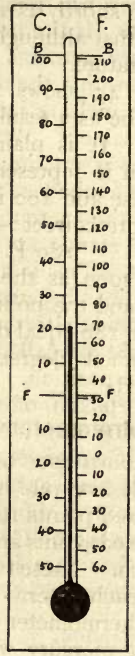

FIG. 45.—A thermometer reading both Centigrade and Fahrenheit degrees.

Suppose our mercury tube is in melting ice and the vessel containing it is heated—usually the tube is fitted into a flask as shown in Fig. 44—then the ice changes to water, and as it becomes hotter and hotter the mercury in the tube rises higher and higher. When the water boils the mercury will have reached a certain height and there it stops. This happens whenever or wherever pure water is boiled; it is a second fixed point.

This second fixed point is the temperature of pure boiling water—it might be called the boiling-water position. It is spoken of in two ways: one hundred degrees Centigrade, or two hundred and twelve degrees Fahrenheit, written shortly as 100° C. and 212° F. It must be remembered that although there are two names there is only one temperature.

Fig. 45 shows file markings (F.F. and B.B.) made on the tube as a result of placing it in melting ice and boiling water. It is plain that the same length of the mercury column is represented by 180 divisions, called degrees, in one case and 100 in the other. The following statement is therefore correct:—

180 F. divisions = 100 C. divisions.

As soon as the tube lying between the melting-point of ice and the boiling-point of water has been divided into 100 or 180 equal divisions, for reading either Centigrade or Fahrenheit degrees of temperature, the thermometer is finished.

A Thermometer is a Graduated Rule.

A comparison between a rule and a thermometer will help. A scale foot rule is a graduated piece of wood or metal with two fixed points represented by 0 and 12, and between these two fixed points are smaller equal divisions called eighths of an inch. These two fixed points do not vary in their distance from each other.

A thermometer is a graduated piece of glass tubing containing mercury with two fixed points represented by 0, or 32, and 100, or 212, and between these two fixed points are smaller equal divisions called degrees. These two fixed points do not vary in their distance from each other if the bore and bulb of the thermometers are alike.

Centigrade means divided into hundredths, so in this method of dividing the distance between melting-ice point and boiling-water point there are 100 spaces. Celsius suggested this method of dividing and numbering the distance, but Fahrenheit, a Dantzig philosopher in 1714, before Celsius suggested his method, had divided the space into 180 parts, starting at 32 and ending at 212. He believed that 0° on

his scale—32° below freezing-point—was the lowest temperature experienced on the earth. Fahrenheit's method is used in ordinary daily life and Celsius' method is used in scientific work. It would be much better if there were only one method for all purposes. This duplication of methods of measuring is unfortunate, but it is not confined to temperature alone.

A table of relations between height of the mercury column above the melting-ice position and degrees of temperature might be made as follows:—

Height.	Temperatures.
Nil	0° C. 32° F.
One-fourth	25° C. 77° F.
One-half	50° C. 122° F.
Three-fourths	75° C. 167° F.
Full length	100° C. 212° F.
Double length	200° C. 424° F.
Treble length	300° C. 636° F.

Thermometers may be obtained which are graduated up to 600° F. and 360° C. This extension of graduation to read higher temperatures than 212° F. and 100° C. and lower temperatures than 0° F. and C. is based upon adding divisions on the stems of the thermometers with spaces between them equal to those between freezing and boiling-points.

It is well to keep in mind in any statements of temperature that the degrees tell us how much the substance is above or below the temperature of melting ice, a temperature often reached in our latitudes. Most common temperatures lie between the temperatures at which water either changes to ice or to steam.

Some Interesting Temperatures.

	F°.	C°.
Bunsen burner, maximum	3400	1870
Human blood heat	98·4	37
Greatest arctic cold (Amundsen)	− 111	− 61·7
Real zero, no heat in substance	− 459	− 273

The sign −, called minus, placed before a number re-

presenting degrees means that number of degrees below 0° C. or 0° F. Compare 1915, the present year's number, with 1915 B.C.; the sign B.C. must be added to signify to which of the two we refer.

Experiment.

Take a Centigrade thermometer which has been in the air and compare its reading and graduations with the one shown in Fig. 46. Notice the points necessary to answer these questions :—

(1) Is the thermometer shown a Centigrade one? It has been hanging in the air on an April day.

(2) How many degrees are there between two neighbouring marks?

(3) Would it be of any value for finding the boiling-point of water?

(4) What is the temperature it reads?

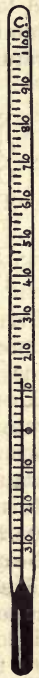

FIG. 46.—A thermometer.

Underground Temperature.

The temperature of the rocks, through which the shafts of a mine are sunk, increases as their depth increases, and it may generally be said that there is an increase of 1° F. for each 60 feet that the shaft goes down. The temperature below will therefore be greater than it is on the surface.

Example.

The ordinary temperature of a South Yorks Colliery is said to be 80° F., the temperature being taken by a thermometer fixed in the coal. This particular colliery is 1800 feet deep, which gives a rise of 30° F., due to the depth, as the thermometer on the surface read 50° F.

On a particular day the temperature at this colliery at the surface was found to be 51° F., which with the 30° F. added gives 81° F. for the temperature of the workings; actually it was 80° F. It should not be expected that the rule of 1° F. for 60 feet of depth would always give the exact underground temperature even in this colliery; there is such a thing as a local source of heat in a mine.

In this particular mine there was a section which showed in one day a temperature of 104° F. In the same section a heading was found with a temperature of 176° F. A temperature of 115° F. had been registered in the same mine, and it is as well to remember that it is possible for a brisk ventilating current to develop heat, if not fire. As a matter of fact over sixty fires have occurred in this mine in four years, and in many cases without smoke; it is therefore to be expected that 1° F. for every 60 feet of depth will not hold where there is chemical action between air and some of the material of the pit. At places where there are no mines and no chance of material getting heated, a rise is found of 1° F. for about 60 feet of depth; it therefore seems that the earth generally gets hotter as one gets closer to its centre.

Practical Application to Mining.

The thermometer or temperature measurer is an instrument well known to those who work in mines. The Coal Mines Act requires that a thermometer shall be placed above ground in a conspicuous position near the entrance to the mine.

Underground the thermometer is used for taking the temperature of the workings and sometimes, by placing the instrument in a hole bored into the coal or rock, for ascertaining the temperature of the ground.

When exploring a mine after an explosion or fire the exploring parties would carry pocket thermometers for testing the temperature of the mine at various points.

Thermometers are very useful in cases of goaf heating due to spontaneous combustion. The men whose business it is to look out for heatings and fires carry these instruments with them and take readings at various points which are recorded, thus giving information which is sometimes very valuable.

In the minutes of evidence given before the Departmental Committee on Spontaneous Combustion in Mines some interesting accounts of temperature measurements are given. At one colliery in North Staffordshire when heating is suspected, rods of iron $\frac{3}{8}$ inch to $\frac{1}{2}$ inch in diameter and 8 to

10 feet long are thrust into the goaf packs, left there for a short time and then taken out and examined by feeling them. This is done to try and find whether heating is going on in the pack. At the same time that these observations are being taken a thermometer is brought into use to find the progress of heating; it is first hung at the coal face and the temperature taken, then taken into the suspected waste or goaf; the readings are booked and kept for future reference.

Another method is to use thermometers inserted in tubes with the ends sealed and pointed. These tubes are driven into the goaf and kept there for some time when they are taken out and the thermometer readings noted.

It is often necessary to know the temperature of the feed water for the boilers, of the gases in boiler flues and chimneys, and of the boiler furnace.

When the temperature to be measured is very high, a special kind of thermometer called a pyrometer is used.

In the British Coal Dust Experiments special instruments were devised for directly measuring the temperature of a coal dust explosion.

Owing to the very brief space of time taken by an explosion it is very difficult to measure its temperature directly by ordinary means, but by using special instruments the temperature of explosion of high explosives such as dynamite may be calculated.

Sometimes a continuous record of temperature is required and instruments are made which give this record in the form of a line drawn on squared paper.

QUESTIONS.

1. The bonnet of a lamp is found to have a temperature of 100° F. Will it be any different in size from what it was when cold? Why is the bonnet of a lamp made of metal?

2. Why is it that in a chimney flue there is an uprush of air when there is a fire in the grate, and very often a downrush when there is no fire?

3. There are two pokers, one made of zinc and the other of iron. When no fire is in the grate there they are equal in length, will they be of equal lengths as they arrive at 260° F. due to a fire?

4. How will you find the temperature of the following: (*a*) A cup of tea; (*b*) the temperature of your lamp; (*c*) the coal face; (*d*) water in the mine?

Have you any idea of what these temperatures would be?

5. Explain the meaning of freezing-point and boiling-point; what is the idea implied in the word "point" in each expression?

6. What temperatures correspond to 140° C. and – 40° F.? Why in such classes of work as steel bridges, steam pipes, boiler furnace tubes, should consideration have to be given to changes of temperature? In which should the allowance be greatest? What would happen if no allowance were made?

7. Do you think the holes of wire gauze become larger on being heated?

8. A cubic inch of steam comes out of the flask (see Fig. 44) and passes into the air; will its volume and density change? If so, explain why.

9. How many degrees are there between any two consecutive lines on a thermometer? What alteration would have to be made to a thermometer to make it read a difference in temperature of $\frac{1}{10}$th of a degree?

10. Suppose you have a brass ring through which just passes a tally check. What experiments would you perform to show that the tally expands and contracts on heating and cooling? What effect will heating have upon the size of the hole in the tally?

11. Keeping in mind the meaning of boiling-point, what would you expect to be meant by the phrases melting-point and ignition-point?

12. Discuss the value of the sense of feeling and of the eyesight in judging the temperature of a body; the former by the sensations we get on touching bodies and the latter by the colour of hot bodies. Do you think they are exact enough to measure temperature? Are these ways more exact in measuring temperature than a thermometer?

13. Do you think the density of the air in this room is uniform, i.e. the same throughout, when (1) it is daytime; (2) it is lighted up by gas? Give reasons.

CHAPTER V.

THE PRINCIPLE OF THE SAFETY LAMP.

It is necessary to have a light in the pit for working purposes, and many have been the devices for supplying it. In the year 1750 Spedding invented his steel mill to give a stream of luminous sparks as a safer way of lighting than the tallow candle. Then in 1815—a century ago—Davy invented a lamp to give a better light and to be much safer, and about a century after that comes the miner's electric lamp. The flame safety lamp is to-day the most popular; it was originally constructed on the scientific principle of using a metal gauze to keep the lamp cool, so as not to ignite any gas in the mine.

It is this scientific principle which we have to thoroughly understand, and its intelligent grasp can only come from experimental knowledge of the action of a metal on heat.

A naked light in a mine is a danger because there is often in the atmosphere around it sufficient inflammable gas to be fired by the light, then there is an explosion. The problem is to devise a method of protecting from the flame of the lamp the inflammable gas in the air around. This would be easy if we could shut up the flame in a glass case and keep out all air and gas, but a flame must have a supply of air for its continual burning. It must also have a case that will let out the impurities produced by the lamp flame.

The difficulty is therefore how to give the lamp a good supply of air, how to let out the impurities, and yet at the same time to keep inside the lamp the flame of any gas which has got inside and become lighted by the lamp flame. A flame surrounded by a gauze would let pure air in and foul out, but it would also let gas and coal dust into the lamp. Would the gauze have any power of shutting off from the outside air flame produced by gas burning inside the gauze? Davy showed experimentally that it could

be relied upon to do so to a certain extent. If you look at one of the first lamps made by Stephenson or Davy (see p. 99), you will see the light is surrounded in the latter by a gauze. At the present time the gauze in a lamp is not easily seen, it has become two gauzes hidden in the bonnet of the lamp; glass is now used for letting out the light. These changes of structure and arrangement still leave the gauze there, embodying the old principle upon which the safety lamp was built. It is necessary to notice that in an oil safety lamp no inflammable gas is produced *inside* the lamp and gauze, and as the lamp flame is far from the gauzes they cannot become by its action very hot. If, on the other hand, inflammable gas and coal dust pass into the lamp through the gauzes, they may be ignited by the lamp flame forming an intensely burning mass of material in the gauzes of the lamp; it is the flame of this that requires keeping inside. May its heating power on the gauzes in some way be decreased so that neither by flame passing through nor by gauzes getting red hot can the outside gas be exploded?

If the inflammable gas and coal dust after getting in the lamp can be burnt without being dangerous to that still outside, then the gauze achieves a wonderful result. Compare the idea with that action of glass, as used in greenhouses, by which heat can get in through the glass but it cannot as easily get out again; the sun's heat is shut up after streaming through the glass.

Experiment.

Fix a short piece of candle on to a small wooden base (see Fig. 47) and then make a cage of a piece of standard wire gauze about 4 inches high × 2 inches diameter, the wooden base forming the bottom of the cage. Instead of making a gauze cage one of the gauzes from a miner's lamp may be used. Light the candle and then cover it with the metallic cage. Take a Bunsen, turn on the gas to a small extent and allow the unburnt gas to play on the gauze. The gas which penetrates the gauze will burn but the flame of the burning gas will not spread to the burner. As the gas is moved

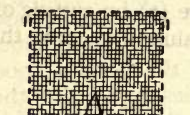

FIG. 47.—Gauze cage on a wooden block.

across the cage slight "pops" will be heard, due to the exploding gas.

It is important to emphasize in this experiment, and also in the general statement of the action of the gauze in the miner's lamp, that the flame of the gas which has penetrated the gauze is the one we want to keep in bounds.

The keeping inside of the flame of the burning gas in the experiment so that it does not strike through and ignite that coming from the burner, is due to the cooling action of the metallic gauze on the flame. This is the action we have to explain. The experiments following will therefore be designed to illustrate the power of metals to take heat from hot bodies and so keep their surroundings cool; this is the secret of the power of gauze to confine a burning mass of gas.

There will in the foregoing experiment be a heated current of air rising up from the gauze; it is pushed up by the cold air underneath which of course takes its place and gets heated. This uprush of air currents robs the cage of its heat and so helps in the cooling process. In the miner's lamp there is an uprushing current, and this must help to cool the bonnet, and in its turn the gauzes. Some of the experiments will show how, by air rising up and carrying heat away, parts of the miner's lamp will be helped to keep cool, despite the fact that the lamp flame is always producing heat as well as light.

Moving Air carries away Heat.

A burning mass of gas or vapour may be extinguished in two ways: (1) by lowering its temperature (2) by cutting off its air supply, both of which may be of value in keeping the burning in its place.

Experience.

The familiar way of "blowing out the candle" consists of lowering the temperature of the flame by a current of breath; in this way sufficient heat is removed from the flame to cool it to a temperature at which it cannot burn. The cooled vapours may often be seen and smelt immediately after blowing out the candle.

The blowing out of all flames, match, candle, or gas, is brought about by establishing a current of air and so

robbing them of heat. Each flame is reduced to such a low temperature that it cannot ignite the fresh vapour or gas which feeds it and so comes to an end.

The foregoing piece of experience is important to our present chapter. The cutting off of the air supply is of less importance, it is fully dealt with in Chapter II.

Experiment.

Take a thermometer and blow a stream of cold air across the bulb, or expose it to a wind. Notice the lower temperature that it shows after the action.

This proves that as air passes over a body it carries off heat; it happens whether the body is a solid, liquid, or a gas flame.

Take a block of wood, B (Fig. 48), place on it a big drop of water and then a thin watch glass or thin vessel, C. Place in the glass a small quantity of carbon disulphide, or ether. From the nozzle of a bellows, N, drive a current of air over the surface of the liquid, and notice very quickly the water turns to ice and B is fixed to C.

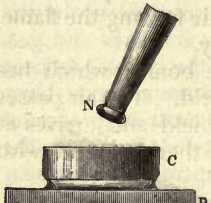

FIG. 48.

The explanation of the result is as follows: the liquid in the glass is a very volatile one and is therefore easily carried away by the current of air as vapour, but to turn a liquid into vapour requires heat. The heat necessary comes from the supports of the glass one of which is water, and this declares its loss of heat by turning to ice.

Experience.

Liquids and solids are often cooled by currents of air being blown across them, e.g. if a plumber over-heats his soldering-iron he will cool it in this way. A similar method is used in cooling tea.

The foregoing experience and experiment prove that air carries away heat from a body as it blows across its surface. It is necessary to realize that any hot body will produce a current in the air around it and in this way start an

air movement which will take away its heat, and so reduce its temperature.

Experience.

The up-draught in the chimney flue and the flow of air into a room are caused by the heat of the fire. This circulation of air goes on as long as there is a fire; it cannot be stopped if the fire continues. The draught carries a great deal of the heat of the fire with it.

These currents of air caused by a hot body which carry away its heat are shortly spoken of as "convection currents". The air is the vehicle or conveyance by which the heat is carried away, and so the phrase is a good one; it suggests to the mind actually what happens.

Air rushing up round a flame cools it, lowering its luminosity and temperature; this effect has caused the production of a patent gas burner which heats the air feeding the flame, so as not to destroy any of its luminosity.

In some lamps for miners, under the bonnet which has intake holes for air, there is an inside shield. The air passes through these holes, strikes the hot shield and arrives at the flame well warmed; the flame is therefore fed with warm air.

Removing Heat by a Metal.

The cooling of flame whether produced by carrying off its heat by blowing over it, or by a metal in contact with it, will result in the diminution of its brightness, and in a more or less pronounced tendency to smoke.

FIG. 49.—A piece of metal leading heat away from a flame.

Experiment.

Obtain an iron weight, or a laundering iron, and bring one of its faces close against the face of a flat flame; its luminosity will almost disappear. The presence of soot and moisture on the iron should be noticed.

The flame gives some of its heat up to the iron, the latter being a metal which readily takes heat away. The heat necessary for making the soot particles highly incandescent is thus lost to the flame, and so instead of their burning away to an invisible gas they collect on the face of the iron.

Experience.

A very similar deposit of soot is often seen at the back of the fire-grate where it forms as a thin hard cake. It may finally take fire, appearing on the back as smouldering lines of fire.

The cause of the deposit is due to the cooling of the flame of the burning coal; the cool air flowing in above the fire keeping the upper part of the fire-grate back fairly cool.

The deposit of black substance found on the gauze of a lamp which is not kept clean is caused by too high a flame, which striking the gauze is cooled, and so soot particles are deposited.

Experiment.

Take some copper wire about $\frac{1}{16}$ inch in diameter and coil it round a lead pencil, making it into a spiral of about eight turns. Leave a piece as a handle (see Fig. 50). Take a candle burning with a short clean wick and bring down the spiral quickly on the flame. The candle will be extinguished. Bring the spiral to a red-hot state by heating it in a Bunsen flame, repeat the experiment, and notice any different result.

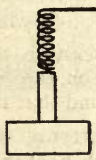

FIG. 50. — Leading heat away from a flame by a copper spiral; the candle is fixed on a block of wood.

Repeat the experiment with a spirit lamp flame.

The explanation of these occurrences is not difficult. If a flame is to be kept burning it must be kept hot; it requires to be kept at a high temperature. The flame keeps itself burning by the heat it produces, but the introduction of the copper spiral robs the flame of its heat, and so it is extinguished. When the spiral is made red hot, previous to its surrounding the flame, there is no extinction of the latter. The student should notice that the spiral does not extinguish the Bunsen flame when he is

making it red hot; in this case the spiral is not large enough to rob the flame of sufficient heat.

The spiral only touches the outside of the flame, but it conveys heat away so rapidly that the whole of the flame gets cooled. It therefore seems that a metal cage, such as the spiral is, robs the flame of so much heat that it is extinguished.

The experiment suggests that if a flame were inside a cage made of metallic gauze and it came into contact with the gauze the flame might be so reduced in temperature that it would be extinguished, or at least where the flame and the gauze met there would be such a cooling of the flame that *as flame* it would not get through the gauze.

Experiment.

Take a thermometer and read its temperature, then lay the bulb of the thermometer on a flat iron, read the temperature again, and notice any difference in the two readings.

Experience and experiment teach that a cold solid, particularly a metal, may rob a hot body of its heat.

Experience.

Most people who have had to make a fire quickly in the ordinary fire-grate and have placed pieces of coal on the fire previously to the wood getting well lighted have found that the burning wood is often put out.

The coal robs the flame of the wood of so much heat that continued burning is impossible.

Experience.

It is well known that if a poker is left in a fire for a length of time the handle becomes hot.

In this case the heat has passed along the poker, and as a poker is made of metal it follows that a metal will take away heat from the fire, allowing heat to flow continually from the end in the fire to the handle in the air.

The next experiment will teach us that metals differ in the ease with which they allow heat to flow through them.

Experiment.

Take two pieces of wire, one copper and one iron, $\frac{1}{8}$ inch thick and 6 inches long, and beat each out flat at one end. Place the wires on a support and clamp the latter on to a retort stand, at a height so that the circular ends may be placed in a Bunsen flame in equal conditions (see Fig. 51). Place a small piece of phosphorus, or a match-head, on the beaten-out ends. Take the time required for each piece of phosphorus to ignite. Or pass a match-head slowly along the wires towards the flame; notice the distance from the flame where each match ignites.

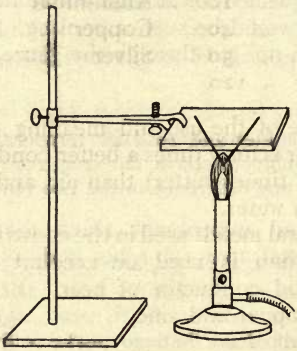

FIG. 51.—Comparing the power of leading away heat: arrangement of the two wires, or rods, in the hot part of the flame equally.

Phosphorus will ignite always at the same temperature, and the temperature at which a match ignites will be the same for any match taken from the same box. If therefore the copper wire ignites the match at a greater distance from the flame than the iron wire does, it means that its temperature is higher at a greater distance than along the iron wire. The experiment shows that heat travels along the copper and goes further than it does along the iron; therefore the copper is said to be a better conductor of heat.

In a well-arranged and carefully managed experiment it can be shown that copper is 4·8 times better for conducting heat than iron. As copper and iron are used in the making of lamp gauzes the experiment should be interesting to us. Kettles are made of these two metals, and it is

a well-known fact that, for boiling water, a copper kettle is more economical in the consumption of gas than an iron one.

The experiment might be used to show that any two metals differ in the ease with which they allow heat to flow along them. The following figures show that this difference in conducting heat extends to other things:—

Air	1	Iron	4,000
Paper	2	Zinc	5,600
Wood	6	Brass	6,000
Glass	10	Aluminium	6,800
Water	40	Copper	19,200
Sand	50	Silver	20,000
Stone	120		

As an example of the use and meaning of these figures, we may say water is forty times a better conductor (and silver twenty thousand times better) than air, and iron a hundred times better than water.

There are several metals used in the construction of miner's lamps. Aluminium is used on account of its lightness, and it is a good conductor of heat. Brass, which is a metal made of copper and zinc, is very largely used; it is a good conductor of heat.

Bonnets are made of steel (a strong variety of iron) or aluminium. Some lamps have a galvanized steel case, i.e. steel plated with zinc.

We have all noticed when metallic bodies are grasped by the hand they give a sensation of cold, whereas wooden, cardboard, or cloth bodies do not. A lamp-post in the open air seems to have a lower temperature than a telegraph-post close by, but they are both at the same temperature on account of being in the same air.

The explanation of the foregoing facts is that the heat of that part of the hand grasping the thing made of metal is led away, and although a fresh supply of heat comes to that part of the hand from the blood it is also led away. The hand therefore having its heat constantly taken away feels cool; to accomplish this the metal must allow heat to travel quickly along it; in short, it is a conductor.

Action of Gauze on Flame.

Experiment.

Take a big beaker or other wide-mouthed vessel and place over its mouth a piece of copper or iron gauze. Ignite in a dish or spoon a small quantity of methylated spirit and pour it into the beaker through the gauze ; the dish may be held by crucible tongs. As the spirit passes through the gauze the flame will be extinguished.

If the burning spirit be poured through the air into the beaker with no intervening gauze then it will not be extinguished. The extinguishing action of the gauze can be accounted for by its leading off the heat so quickly from the burning mass that the temperature is lowered and continued burning is not possible.

Experiment.

Take a Bunsen (see Fig. 52), burning with a non-luminous flame, and lower a piece of lamp gauze slowly on the flame ; notice that the flame does not pass through until the wire gauze gets very hot. Turn off the ignited gas and allow a stream of unburnt gas to play on the gauze. Try and light the gas on the upper side of the gauze, it will ignite but the flame will not strike through and ignite the gas under, or inside, the gauze screen.

Obtain a piece of gauze which has had some of its meshes broken away and test its power to resist the passage of flame.

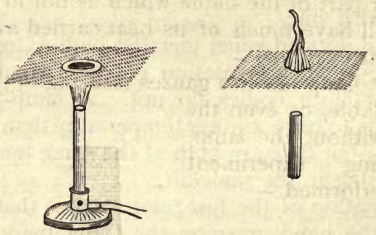

FIG. 52.—Gauze stopping burning gas from igniting unlit gas on the opposite side.

The first part of the experiment shows that the gauze stops the flame from passing through until it gets red hot; the passing through is helped by the force of the flame and

the up-draught of the air. In a miner's lamp these two actions would not help in such a forcible manner, even when the gauze gets red hot by gas burning in them.

These experiments on gauze and Bunsen gas are intended to illustrate the shutting up of burning gas which has found its way from the outside into the gauze of the miner's lamp, and not any action of the gauze on the *lamp flame*.

It is important to notice in the experiment that the gauze breaks up the flame as it attempts to pass the meshes, and though the flame, by its being flattened slightly covers, say, 3 sq. inches of the gauze, there are, nevertheless, 2352 meshes, so the flame is split up into that number of parts. These small tongues of flame are well cooled by the mesh around them, on account of its good conducting powers for heat, and so cannot get through; they are extinguished in the attempt. The uprising current of air also carries with it a great deal of the heat of the gauze so helping to cool the tongues of flame.

In the second part of the experiment the flame will very seldom, if at all, strike through to the burner underneath; the gauze does not get hot enough. The gauze is rapidly conducting away heat, and there is only that from the base of the flame to remove. It is thus very different from the first part of the experiment where the whole of the flame helps to heat the gauze.

The upper part of the flame which is not in contact with the gauze will have much of its heat carried away by rising currents of air.

A Marsaut lamp has two gauzes (see Fig. 53). If such a lamp is available, or even the two gauzes without the lamp, the following experiment should be performed:—

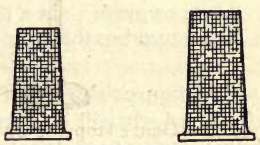

FIG. 53.—Inner (left) and outer (right) gauzes of a lamp.

Experiment.

With a pair of tongs take hold of the flange of the inner gauze and bring it down on to the flame of a Bunsen burner. The gauze will in time become hot and the flame will pass

through, as it does in the experiment with a flat gauze (see p. 92). Let the inner gauze cool and then fit it into its outer gauze. Now hold the double gauze over the Bunsen flame and see if the flame gets through.

The flame will probably be quite unable to pass through the double gauze; this is a real shutting up of flame. The advantages of such an arrangement in a fiery mine will at once be seen by any one who has realized how a flame may ignite a gas, and the lighting of the house gas by the flame of a match makes every one familiar with it.

The following details are helpful in forming an idea of the action of gauze and should be corroborated by measurement of a piece of standard iron-wire gauze. The Safety Lamps Order of 1913 says every lamp gauze must have 28 meshes to the lineal inch (784 to the sq. inch).

Experiment.

Measurements of a piece of iron gauze 6 inches square :—

Lengths of wire $28 \times 6 \times 2 = 336$.

Total length of wire $336 \times 6 = 2016$ inches, a little longer than two and a half times the length of a standard cricket pitch, which is 22 yards.

A length just wrapped round a piece of glass tubing ten times and pushed together measured ·15 inch in thickness. The diameter of the wire is therefore ·015 inch.

Area of surface $= 2016 \times 3{\cdot}14 \times {\cdot}015 = 94{\cdot}75$ sq. inches.

Adding ·25 for the area of the ends we may say 95 sq. inches.

Weight of the 6-inch piece = $1\frac{3}{4}$ oz.

Thickness of wire in a lineal inch $28 \times {\cdot}015 = {\cdot}42$ inch.

Space or mesh in a lineal inch $1 - {\cdot}42 = {\cdot}58$ inch.

The gauze has therefore more mesh area than wire area.

The figures show that if a small block of iron weighing $1\frac{3}{4}$ oz., which will be about the size of a small strawberry, is drawn out into a length of 2016 inches, a surface of 95 sq. inches is obtained—about three times the size of this page. This big surface puts the wire in a good position to lose the heat that it receives.

Experiment—To Illustrate the Action of Gauze.

Take a block of wood and fix into it a number of small brass-headed screws or tacks closely packed so as to represent gauze (see Fig. 54). Level off any unevenness of surface by a file or stone. Paste a sheet of paper on the block and when dry hold it over a Bunsen flame for a few seconds and notice any charring of the paper.

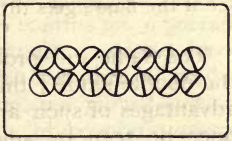

FIG. 54.—Screws and interspaces to represent gauze.

The charring of the paper will depend on its getting heated, but if the heat be quickly and regularly led away from the paper by the metal then charring cannot occur. The wood does not lead away the heat and so the paper over it quickly chars. Brass is therefore a better material than wood for leading away heat (see the Table on p. 91).

Let us try and follow what happens as the heat leaves the flame at those places where there are tacks. The heat passes through the paper and is quickly led away along the tack, and if the points of the tacks go through the block, as they should, then the heat will pass into the air. It is of great importance to know whether the air remains fixed and the heat is discharged into it, or if it moves away and carries heat with it. If the latter is true then the heat will not accumulate around the ends of the tacks for the air, as convection currents, will move away with the heat taken up by it.

Cooling Hot Bodies by Metallic Surfaces.

The cylinders of small engines in which mixtures of gas, or petrol vapour, and air are fired would become very hot if no devices for cooling were used. In the engines of aeroplanes and motor cycles fins or ribs are cast on the cylinder so as to help the cooling of the latter; the bigger the surface exposed the sooner the engine gets rid of waste heat. Travelling through the air is a great aid to cooling.

In motor-cars there is a radiator in front of the car on which are fins or ribs for helping the cooling of the water which brings heat away from the cylinder of the engine.

This water can be used over and over again for taking away heat from the cylinder.

The foregoing instances should help us to realize that having a big surface exposed to the air helps a hot body to cool quickly. Compare these devices with that of having $1\frac{3}{4}$ oz. of iron, less than half of a cubic inch, made into 2016 inches having an area of 95 sq. inches for cooling the hot gases produced in a miner's lamp. Spreading out a hot body to the air greatly assists its cooling—the surface of the bonnet is an illustration of such.

By experiment and experience it has been shown that a heated body may lose heat in two ways—by the air *carrying* heat away as it *moves* from the body, and by a *fixed* part *leading* heat along it more or less easily according to power called conductivity.

Air is a good carrier but a poor conductor (see p. 91); it can move because it is a gas. A solid cannot move, it cannot therefore carry away, it can only let heat flow along.

An Illustration of Conduction and Convection.

Imagine a large reservoir of water from which are laid pipes to distribute the water to a district. Then for this purpose we may say that the pipes lead or conduct the water from the source; they are conductors of water. The reservoir may also lose water in another way—by winds blowing across its surface, carrying with them moisture. From this point of view the moving air is the vehicle by which water is removed; it is analogous to a convection current of air carrying away heat from a hot body.

Both conduction and convection help to keep a miner's lamp cool. There is a third way by which heat may be lost by a body; this way is the only one by which the sun's heat is lost to it and reaches us.

Air does not fill all the space between us and the sun, so there can be no convection currents to bring its heat, and there is no solid material in space to conduct it to us. Heat that comes across a space, empty or containing air, and does not heat it, is spoken of as radiant heat; the process is known as radiation.

A room with a fire is not alone heated by convection currents of air, but by heat cutting through the air inde-

pendently of the latter's existence, i.e. by radiation. A lamp will lose heat by conduction through the metal by convection in the air, and by radiation through the surrounding space.

Convection Currents.

The movement of air and its power of carrying away with it heat is taken advantage of in ventilating public rooms; Fig. 55 shows a ring of gas burners under a large funnel, its flue projecting beyond the roof into the outer air.

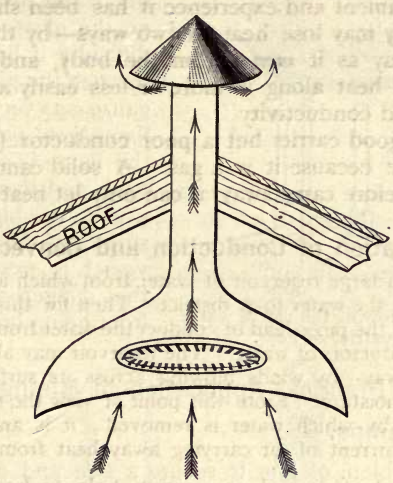

FIG. 55.—The arrows denote the general direction of the currents.

The heat of the gas is therefore carried away by convection currents of air; their directions are shown by arrows.

A liquid like air can move when heated and so carry heat by its currents. These currents may be easily seen if a substance which only dissolves slowly is put in the liquid.

Experiment.

Fit up the apparatus shown in Fig. 56. Fill the flask with water, drop into it a few crystals of permanganate of potash, and then heat with a small flame.

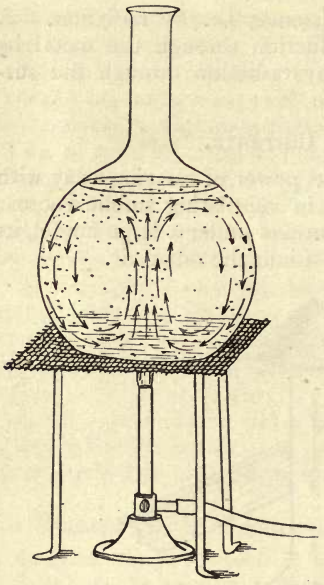

FIG. 56.—Showing the use of water as a carrier of heat.

Heat is carried about by the moving water currents; their directions are shown by streaks of coloured water.

The gauze is used over the burner (as in Fig. 56) whenever a thin glass vessel is being used for heating a liquid, as it prevents the flame playing directly on the glass, owing to the difficulty it has in getting through the gauze. If the gauze gets very hot and the flame gets partly through, the flame is still well kept back and therefore cannot usually rise higher than the surface of the water, so the vessel is preserved from this danger and probably from being broken.

Practical Application to Mining.

Safety Lamps.

The problem of how to secure a safe and efficient light for the miner has engaged the attention of mining and scientific men for nearly two hundred years. Owing to the use of naked lights in mines where inflammable gas was present in dangerous quantities many serious explosions occurred. In 1740 the steel mill, a device for lighting gassy mines, was introduced by Spedding; this consisted of a steel wheel driven by hand by means of gearing which on being rotated rubbed against a flint and threw off a shower of sparks. The light obtained in this way was feeble and in some cases the sparks were sufficiently hot to ignite an inflammable mixture of air and gas.

In 1811 Clanny invented a lamp in which the light burned in an airtight vessel, the air necessary for combustion being supplied by a pair of bellows.

In 1813 public opinion had become so aroused by the frequent occurrence of colliery explosions that a society was formed in the North of England with the object of calling the attention of scientific men to these disasters and of obtaining their help in minimizing them. The result of the labours of this society was seen in the invention of the Davy and Stephenson lamps, and, a little later, the Clanny lamp.

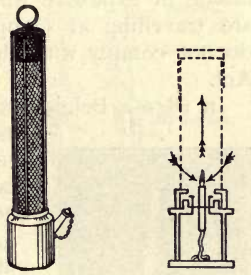

FIG. 57.—Davy lamp, photograph and diagram.

The Davy lamp consists of an oil vessel surmounted by a cage of gauze, the necessary air for combustion passing in and out of the lamp through the gauze.

The Stephenson lamp is similar, but in addition to the gauze is fitted with an internal cylindrical glass with a

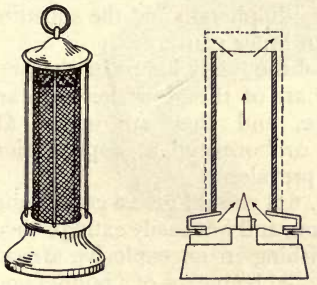

FIG. 58.—Stephenson lamp, photograph and diagram.

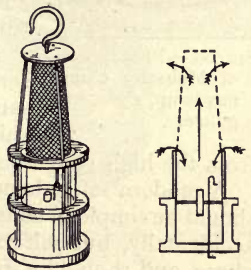

FIG. 59. — Clanny lamp, photograph and diagram.

perforated cap of copper. The air for combustion enters the lamp through a series of small holes near the bottom and passes out at the top of the lamp.

In the Clanny lamp the light is surrounded by a thick glass cylinder surmounted by a gauze, and the air passes into the lamp just above the glass and out at the top.

These lamps are not now used in mines, as they are unsafe in explosive mixtures of air and gas even if such are travelling at comparatively low velocities, and they do not comply with the requirements of the Coal Mines Act.

In 1840 a Belgian mining engineer named Meuseler introduced an improved safety lamp, the improvement consisting of a gauze diaphragm fitting just above the glass and carrying a metal chimney.

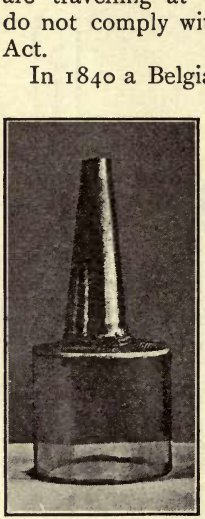

FIG. 60.—Photograph of Meuseler chimney lamp, glass, and gauze.

Air passes into the lamp through the outer gauze, through the gauze diaphragm to the light, and out by way of the chimney. This lamp was found to be safer than those previously described.

It was subsequently modified and remodelled by M. Marsaut, a French mining engineer, the principal alterations being the removal of the chimney and gauze diaphragm and the substitution of an inner gauze.

Most of the safety lamps of the present day are of the Meuseler or Marsaut type, and they are nearly all shielded or bonneted as a protection from the high velocities now prevalent.

A modern safety lamp (Fig. 61) should give a good light, should be simple in construction, and not easily extinguished accidentally, but self-extinguishing in an explosive atmosphere, and should be so protected by means of a bonnet and suitable baffle plates at the air inlets as to be safe in an explosive mixture travelling at any velocity likely to be met with in a mine and striking the lamp at any angle.

It should be fitted with a good lock which cannot easily be tampered with, and should also be carefully looked after

and kept clean, as its safety in the presence of gas depends upon it being in good condition.[1]

It is very important that the direction of the air through a safety lamp should be studied so that in the event of it becoming necessary to extinguish a lamp owing to gas firing or exploding in it, this may be done readily and safely by covering up all the air inlet holes (see Fig. 61) with some article of clothing.

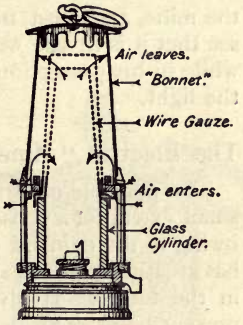

FIG. 61. — Diagram of lamp, showing air currents and construction.

The provisions of the Coal Mines Act require that no light other than a locked safety lamp shall be used in a seam where any return airway contains more than ½ per cent of inflammable gas, or in any seam (except in main airways within 200 yards from the shaft) where an explosion of inflammable gas causing personal injury has occurred within the previous twelve months, or in

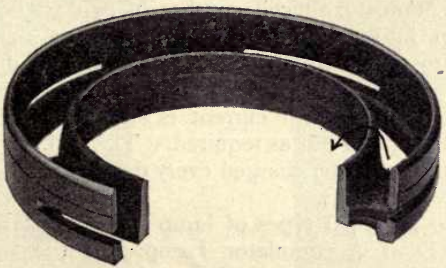

FIG. 62.—Photograph of lamp ring, showing air inlets and baffle plate. The ring is cut in order to show section.

any place where there is likely to be any such quantity of gas as to render the use of naked lights dangerous.

Lamps must not be unlocked underground except at the appointed lamp station, which must not be in the return air.

[1] For particulars and drawings of modern lamps see Safety Lamps Order issued by Home Office, Form 886.

A person using a safety lamp must examine it externally and see that it is locked and in good order before entering the mine, and must from time to time examine the lamp to see that it is in safe working order. If the lamp is injured while in his possession he must at once carefully extinguish the light.

The Electric "Miner's Lamp".

The portable electric lamp has been used in mines to a small extent for a considerable number of years, but recently, owing to the demand for a better light, the number in use has greatly increased, and appears likely to increase still more in the future. It gives a very good light but cannot at present be used for detecting fire-damp.

The lamp consists essentially of the following parts:—

1. A case, usually of steel.
2. An electrical accumulator or cell.
3. A bulb of glass carrying the wire or filament which gives light by becoming incandescent when an electric current is passed through it.
4. A suitable and efficient locking arrangement.

The accumulator or cell consists of two plates of metal which dip into a liquid. If a current of electricity is passed into one plate through the liquid and out at the other plate, chemical changes take place and the energy expended by the electric current is stored up in the lamp and may be given out as required. The cell of an electric miner's lamp must be charged every day by passing through it an electric current.

The two principal types of lamp are the Alkaline Lamp and the Lead Accumulator Lamp. In the former the liquid used in the cell is alkaline, and the metal used in the making of the plates may be nickel, cobalt, cadmium, and iron. In the latter the liquid used is acid, and the metal of the plates is lead.

Both types of lamp are illustrated in Figs. 63 and 64, which are photographs of lamps now widely used.

The alkaline lamp is said to have a candle-power of 1·75 and the lead accumulator lamp a candle-power of 1·5.

It will be noticed that in both lamps the bulb carrying the light is surrounded by a stout protecting glass which cannot be easily broken.

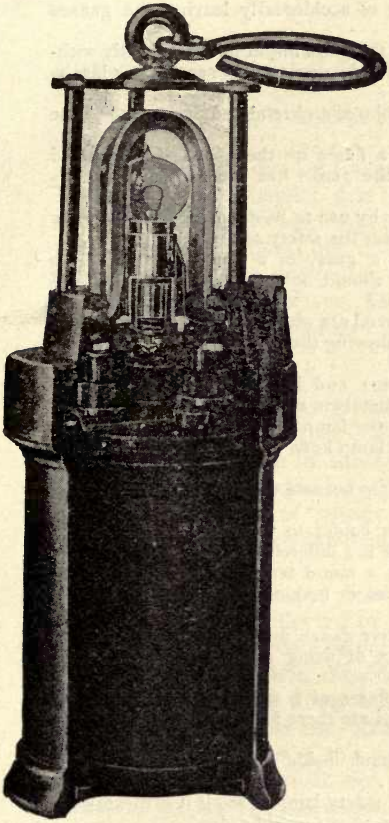

FIG. 63.—Wolf alkaline lamp.

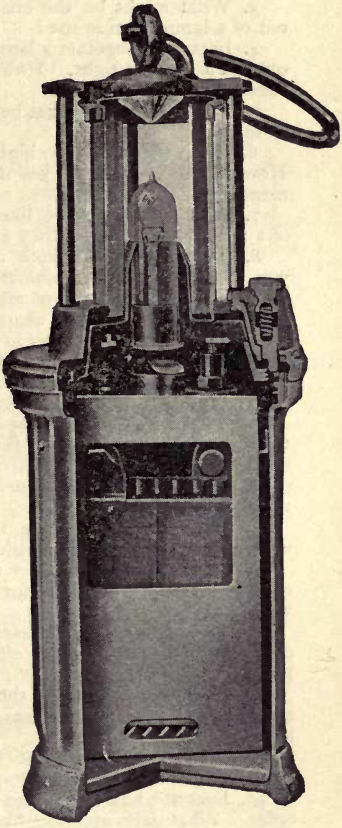

FIG. 64.—Wolf lead accumulator lamp.

QUESTIONS.

1. What are the disadvantages of having too high a flame in a safety lamp?

2. Describe the kind of safety lamp the men use in the mine where you work. Does it differ from that used by the foremen; if so, in what manner?

3. What might be the effect of accidentally leaving the gauzes out of a lamp when in use?

4. In putting together a lamp the glass might be fixed tightly without its being gas-tight. How would you test to see if the glass is fixed gas-tight?

5. How may lamp gauzes be injured and rendered dangerous to use in the pit?

6. What effects has too high a flame on the crown of the gauze? How would you test to see if the gauze has been damaged in this manner?

7. What substances are likely by use to be deposited on the gauze of a miner's lamp? Do they affect the safety of the lamp?

8. Is the mine you work in a gassy or a non-gassy one? Do you think the same carefulness should be exercised by miners and managers in both kinds of mine?

9. Soot, coal dust, and charred oil are often found on a lamp gauze. Do you think there is danger in allowing them to remain on the gauze? What is the danger to be feared?

10. Gauzes are made of copper and iron, as are kettles. Give reasons for the use of these two metals in either article.

11. Where does all the heat of the lamp get to finally? How does the heat get away? Would the lamp keep as cool if the air did not move when heated?

12. Does the handle of your lamp become warm? Account for the result of your observation.

13. Which kind of tub is the colder to the touch—an iron or a wooden one? Explain why there is a difference.

14. What objection is there to a metal teacup? Do you consider copper to be the best metal for use in making cylinders to hold hot water?

15. In what way may a defective gauze differ from a satisfactory one? What might be the effect of using a defective gauze in a lamp?

16. The best height for the flame of a safety lamp is said to be about $\frac{3}{4}$ of an inch. What reasons are there for fixing this as the best height?

17. What gases would be found inside a miner's lamp before and after the lamp is lighted?

18. Describe how to examine a safety lamp to see if it is in working order. What parts are most likely to get out of order?

19. Explain by diagram how your safety lamp gets the necessary supply of air. Do all safety lamps get air by the same method?

CHAPTER VI.

THE MINE GASES KNOWN AS DAMPS.

THE word damp can be traced in the Dutch, Danish, and Low German languages; it is the same word as the German *dampf*, meaning steam, vapour, fog or smoke. At the present time in general life it often means moisture, but in mining it suggests dangerous gases. All the damps are not combustible gases, e.g. black or choke-damp will not burn, they are all dangerous to life.

Choke-damp.

This is the miner's name for the gas carbon dioxide which has been considered on pp. 29-36.

It has been shown in these pages that it is a gas much heavier than air, hence it will accumulate near the floor and at the bottom of sumps or wells. It is known to escape sometimes, like fire-damp does, from the coal-face in very large quantities.

It must be remembered that the accumulation of this gas on the floor will be affected by the ventilating current of the mine, and also by its own power of diffusing. If we imagine a big outburst of carbon dioxide from the coal-face the gas will fall towards the floor, but it will not stay there permanently; as soon as the outburst is over diffusion would slowly clear it all away, the ventilation current would do it quickly. No gas will stop permanently in any place, unless in an airtight enclosure; diffusion always spreads it far and wide.

Choke-damp begins to be objectionable when there is 3 to 4 per cent in the air; at 6 per cent headache is felt. The senses become more or less drugged as the quantity

increases, and 15 per cent renders one unconscious. Death will occur at 25 per cent.

Its action in extinguishing a light is a very valuable and simple indication of its existence in a place.

Marsh Gas or Fire-damp.

Marshes are low-lying pieces of land usually of a swampy nature; the soil of such land generally contains decomposing refuse of a vegetable nature, and all vegetable material when sufficiently decomposed gives off gases, one of which is called marsh gas. This origin of the gas has given it the first name. Decomposing vegetable material accumulates on the bottom of ponds, and if they are not regularly cleaned it rots further and produces marsh gas. If stagnant and dirty pools are watched during a hot summer bubbles will be seen rising to the surface; these are bubbles of marsh gas.

Now coal is vegetable material which has undergone through long ages a certain amount of decomposition, producing marsh gas, which gets liberated and mixes with mine air when the coal seams are worked.

As this gas takes fire when mixed with air it is sometimes called "Fire," which gives the reason for the first part of the word fire-damp.

In olden times, even at the end of the eighteenth century, it was got rid of in mines by setting it on fire. The men set off for this special kind of work were called firemen.

Experience.

That the air in its ordinary state is neither combustible nor explosive follows from the everyday action of striking a match in it, or producing any kind of a light. If it were so, then it would take fire where the light is and spread throughout the atmosphere.

It is plain, then, that mine air differs from ordinary air, inasmuch as a light may produce an explosion, which is very rapid combustion, the whole of the mine air being quickly ablaze. The mine air in these circumstances is similar to ordinary air mixed with coal gas, it having become combustible and explosive.

Fire-damp consists wholly or chiefly of the combustible gas called marsh gas or methane; the other gases mixed with it vary in amount but are generally small. The following figures show the composition of two samples of fire-damp:—

	South Wales Colliery.	Gateshead Colliery.
Marsh gas . .	97·7 per cent	94·2 per cent
Nitrogen . .	1·8 „	nil
Carbon dioxide .	·5 „	nil
Air . . .	none	5·8
	100·0	100·0

We have learnt that air, carbon dioxide, and nitrogen are not combustible, and it is plain therefore that the essential constituent of fire-damp is marsh gas.

The following figures give the action of a light on various mixtures of air and marsh gas. It should be particularly noticed that mixtures rich and poor in marsh gas are not explosive. The first mixture is equal to 28·6 per cent of marsh gas and is rich in the gas; the last one only contains 2 per cent, and is therefore poor; in neither case is there any explosive action when a light is brought into contact with the mixture.

Marsh Gas.	Air.	Action of a Light on the Mixture.
1 cub. ft.	$3\frac{1}{2}$ cub. ft.	No explosion; burns quietly.
„	$5\frac{1}{2}$ „	Explodes gently.
„	$9\frac{1}{2}$ „	Most explosive.
„	13 „	Explodes gently.
„	30 „	No explosion.
„	50 „	No explosion.

The last two correspond to 2 and $3\frac{1}{3}$ per cent respectively, and they can be readily detected as a "gas cap" by the lowered flame of a miner's lamp. Thus both mixtures burn in proximity to a source of light and heat—as the lamp flame—but they will not explode, neither will they continue burning when the flame is withdrawn.

If the actions of a substance have to be learnt it is necessary to get this substance free from others, then we are quite certain that there will be no erroneous conclusions

due to other substances being present. Fire-damp always contains marsh gas and generally other gases, and so if a substance which easily gives off marsh gas unmixed with other gases can be found, we may use it for finding some properties of the dangerous constituent of fire-damp.

To Make Marsh Gas.

Fit up a small flask with a thistle-head tube and a delivery tube passing through the cork. C

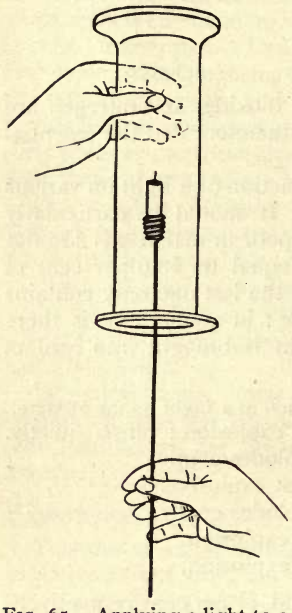

Fig. 65.—Applying a light to a cylinder of marsh gas.

The thistle-head tube should reach almost to the bottom of the flask, and the delivery tube just through the cork (see Fig. 66). Place about 15 gm. of aluminium carbide in the flask and arrange to collect the gas. Pour small quantities of water through the thistle funnel—it may be necessary to slightly warm to start the action—and collect three jars of the gas; keep them inverted. Apply a light separately to the first and second jars. The gas in the first jar may give a slight explosion owing to its being mixed with air obtained from that in the flask. The second jar should be turned upright as soon as the gas has been lighted. Watch the flames pass down the cylinder, then allow to cool, with a cover glass on, and shake up with lime water so as to detect the carbon dioxide produced in the combustion. Push the lighted taper into the third jar (see Fig. 65). In the case of the third jar it will be noticed that there is no explosion; if no air is present the lighted taper will be extinguished.

The foregoing experiments and the method of performing them show that marsh gas is lighter than air, not easily dissolved by water, is combustible, forms an explosive mixture

with air, and on the combustion of it carbon dioxide is produced.

In the combustion water vapour is also formed, but as water is used in making the marsh gas the experiment cannot

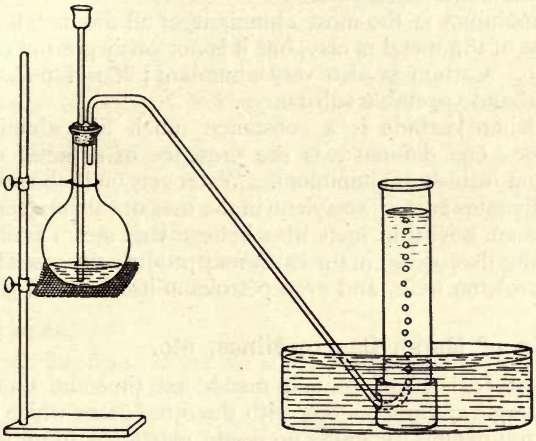

FIG. 66.—Apparatus for preparing marsh gas.

be used to prove its formation in the burning. Some water vapour will come over with the marsh gas, and so collecting it in a dry cylinder, by displacing air, would not prove the point.

Aluminium Carbide.

The name suggests it is made of two substances, aluminium and carbon, and such is the case. Aluminium may be well known to us if we use our observational powers, for it is widely used in making saucepans, kettles, and other domestic metal-ware, and for making parts of petrol engines.

It is a light metal, silvery-white in appearance, and may be strongly heated without undergoing alteration; it is neither affected by hot nor cold water. The foregoing properties should be noted in connection with a saucepan and its work.

Carbon is as well and as widely known as aluminium; it is

our old friend soot, which we know comes from coal. The two substances aluminium and carbon when heated in the electric furnace at about 3000° C. join together to form a new substance composed of them and therefore called aluminium carbide.

Aluminium is the most abundant of all the metals; one source of the metal is clay, but it is not easily got out of this source. Carbon is also very abundant; it is found in *all* animal and vegetable substances.

Calcium carbide is a substance much like aluminium carbide; one difference is the presence of a metal called calcium instead of aluminium. Water acts on both carbides, and liberates gases—acetylene in the case of calcium carbide. There are scientific men who believe that steam acting on carbides deep down in the earth may produce the gases found in petroleum wells, and even petroleum itself.

Origin of Marsh Gas in Mines, etc.

Most coal seams contain marsh gas (in some there are very large amounts) along with the other gases which compose fire-damp. There is no doubt marsh gas in mines has had its origin in the decay of coal; coal seams have been very largely made from leaves and twigs of trees, which by decay produce marsh gas.

There is, as has just been pointed out, a close connexion between the decay of vegetable matter, with no air present, and the production of marsh gas. In the decomposition of wood by heating it in the absence of air much marsh gas is produced, and also a substance called acetic acid. Acetic acid is an acid derived from the vegetable world, and is closely related to another vegetable acid—formic—which easily gives off the most dangerous of all damps—carbon monoxide. In the similar decomposition of coal to get coal gas there is much marsh gas produced.

Marsh gas may be made in the chemical laboratory from acetic acid; the acid is first mixed with soda and so forms acetate of soda. When this substance is heated in a tube and caustic soda is present, marsh gas comes off and may be collected.

Carbon Monoxide Gas.

White damp is the miner's name for this gas; it has the scientific name carbon monoxide. This name, like others in chemistry, tells us the composition of the gas; it contains only carbon and oxygen. Carbon dioxide, which we have studied, is made of carbon and oxygen, but there is twice as much oxygen by weight in it as in carbon monoxide. Compare the prefixes of the words monoplane and biplane to denote aeroplanes having one and two planes respectively.

The close relationship of the two gases in name should be kept in mind; as we shall see one may turn into the other by changing its amount of oxygen. Although carbon dioxide is more common than carbon monoxide it is very likely that we are more familiar with the latter, owing to the striking blueness of its flame.

Experience.

Watch the flame at the top of the street-watchman's fire; it has a blue colour similar to the lower blue part of a luminous gas flame. The same flame may be seen burning when the fire is red-hot in a house grate. The blacksmith's forge will show the same blue flame when the coke on the hearth is red-hot, and air is being forced through the glowing mass. The same blue flame may often be seen burning at the outlet of a smelting furnace flue. This blue flame is in each case the invisible gas, carbon monoxide, burning.

When coal or coke burns with a plentiful supply of air carbon dioxide is produced, and it might be said in the cases given, when we see the blue flame of carbon monoxide, there is a plentiful supply. The contention is quite true, and so the explanation of the discrepancy must be sought for by making an experiment, and in so doing we shall find one way of accounting for the production of carbon monoxide in the pit.

Experiment.

If a piece of glass tubing is filled with coke or charcoal and fixed on a retort stand, as is shown in the right side of Fig. 67, and is slowly heated by a Bunsen burner, whilst air or oxygen is passing through carbon dioxide gas is formed.

The air or oxygen in passing over red-hot charcoal in unlimited quantities brings about combustion of the charcoal with the production of carbon dioxide.

If the glass tube instead of being joined to the iron tube

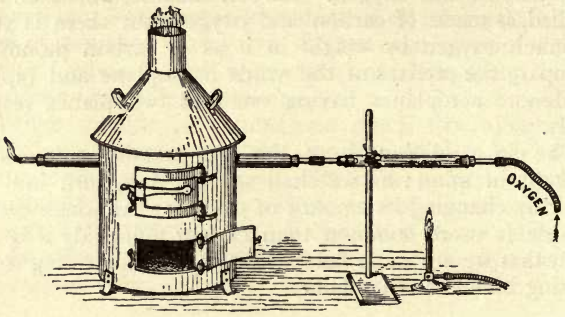

FIG. 67.

of the furnace opened on the left hand into the air and a match were held at the opening, the gas coming through would not ignite; it would put out the light. If the glass tube dipped into a glass of lime water, the latter would become white, again showing the gas to be carbon dioxide.

The Experiment Continued.

Fig. 67 shows on its left side a gas furnace through which runs a piece of iron pipe also filled with coke or charcoal. The figure shows the glass tubing fitted into the iron tube. The coke in the iron tube is made red-hot by the gas furnace, and then carbon dioxide, made in the glass tube, passes through the iron tube. It is found that the gas issuing from the iron pipe may be lighted, as shown in the figure.

The gas coming through burns with a blue flame and is carbon monoxide. This experiment will explain, if thoroughly understood, the formation of carbon monoxide in the house fire-grate, in the watchman's fire, and in the smith's forge. When carbon monoxide is burning at the exit (Fig. 67) the charcoal or coke in both tubes is red-hot and air or oxygen is passing through forming carbon dioxide in the glass tube, which goes into the iron tube full of red-hot coke; this takes

away from the carbon dioxide half of its weight of oxygen and so transforms it into carbon monoxide. When this carbon monoxide gets into the air and burns it becomes carbon dioxide again.

Making a Diagram to give an Explanation.

Represent by a diagram from the following statement a section of a fire-grate. Draw three small circles, representing the bars A, B, C, about the size of the head of a nail, and half an inch above each other. Draw a straight line about half an inch long from the lowest circle C, leaving a few gaps in it to represent the spaces of the under-grate ; from the end draw upwards a line, leaning away from the circles, to represent the back of the fire-place. Fill the grate with the outline of pieces of coal.

With the foregoing diagram follow through this explanation. The air passes into the fire by the under-grate and between the bars B and C ; put arrows in the diagram to represent these two air streams. In these lower parts of the fire the air and coal burn forming carbon dioxide. The carbon dioxide passes forward into the hot mass of burning coal about on a level with the bar B, and gets changed to carbon monoxide. When this carbon monoxide appears at the surface it burns with a blue flame to carbon dioxide. The passage of air through the fire is therefore precisely similar to its passage through the tubes of the furnace ; first carbon dioxide is made and then changed to carbon monoxide, and then again carbon dioxide is produced. So carbon monoxide has only a short existence.

It is important to notice that in each case the flame is produced from either burning coke or coal; the former is made from the latter, so is much the same thing. The same blue flame may be produced by burning paper or wood ; it is particularly noticeable when the material gets completely hot. The foregoing substances are all derived from the vegetable world ; there are some chemicals derived from the vegetable world which by other treatment than burning yield carbon monoxide gas.

It is necessary that we should know a few properties of carbon monoxide, and for convenience other substances than coal or coke will be used for obtaining the gas, but like coal

they come from the vegetable world. There are two acids, formic acid and oxalic acid, from which carbon monoxide can be easily got; the former is the acid found in stinging nettles and the latter one is found in rhubarb. The acids may be used, or compounds of them containing soda, called respectively oxalate of soda and formate of soda. Any one of the four substances—oxalic acid is the cheapest because it can be made from sawdust—when mixed with strong sulphuric acid decompose and give off carbon monoxide.

To Set Free Carbon Monoxide.

Fit up a test tube A, or a small flask B, with a cork and delivery tube (see Fig. 68). Place in the test tube about a salt-spoonful of soda formate and about the same bulk of strong sulphuric acid. Place the delivery tube in water, fill a test tube with water, then warm the mixture and collect a test tube full of the gas. Light it and

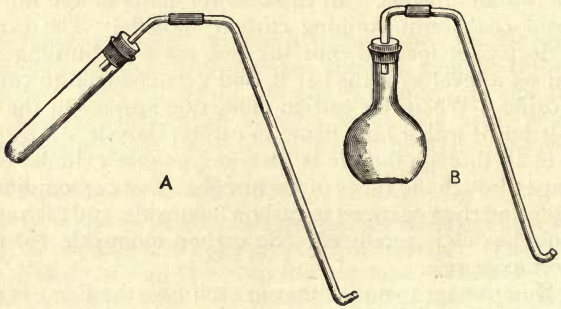

Fig. 68.—Apparatus for setting free carbon monoxide.

notice the colour of the flame, and test the burnt gas for carbon dioxide by shaking the tube after adding lime water.

Show by collecting another tube full that the original gas does not give with lime water a white turbidity.

The gas may be liberated in the same way from oxalic acid; in this case carbon dioxide is also liberated; prove this by the lime-water test before burning the carbon monoxide.

In this case the carbon monoxide may be burnt as it leaves the mouth of the tube containing the mixed substances.

Properties of Carbon Monoxide.

Carbon monoxide is a colourless gas which burns with a blue flame. It is a very poisonous gas, giving the blood a bright scarlet colour. It has no effect in small quantities on a miner's lamp.

Formation of Carbon Monoxide in the Mine.

Mine air invariably contains methane and coal dust, and in the course of an explosion they take up oxygen; if there is insufficient oxygen to form carbon dioxide, then carbon monoxide is produced. If methane could always explode with about ten times its bulk of air—exactly the proportions are 9·38 per cent of methane and 90·62 per cent of air—then carbon dioxide would be produced. In explosive conditions these proportions are not usually found, there is a shortage of oxygen and consequently carbon monoxide is formed. And even if some carbon dioxide were originally formed in an explosion it might get reduced to carbon monoxide; this is proved possible by the Furnace experiment and the changes carbon dioxide undergoes in a grate full of red-hot coal or coke.

Effect of Carbon Monoxide on Man.

Its effects on men are: headache at first, followed by inability to talk, and finally unconsciousness. Any quantity greater than ·15 per cent is distinctly dangerous, i.e. about one cubic inch in 700 cubic inches of air, ·03 per cent, i.e. one cubic inch in 3500 cubic inches of air, will cause giddiness.

Dr. Haldane believes that on an average 70 out of every 100 lives lost in mine explosions are due to poisoning by carbon monoxide; it is plain then that it is formed in explosions and by breathing it the human being is poisoned. In the West Stanley explosion of 1909 when 165 men were killed, the numbers were as follows:—

Killed by carbon monoxide poisoning	121
„ „ violence	25
Other causes of death . . .	19
	165

Blood in the lungs absorbs oxygen from the air in them; this is necessary for life, but in the presence of carbon monoxide it shows preference for the latter gas, despite its poisonous properties. Blood holds carbon monoxide two hundred times more firmly than it does oxygen.

An Analogy.

That different substances may be absorbed and then held with varying degrees of firmness may be illustrated in the following manner. A spot of ink—and ink consists of water containing a soluble black-blue dye—falls upon a piece of material, e.g. cloth, and is absorbed by the material; in time the water evaporates away, but the "ink stain" remains; it is often difficult to remove it from the cloth. Thus the water is less firmly held than the stain, and the cloth, therefore, shows a holding preference for the dye.

Blood in the same way holds carbon monoxide more firmly than oxygen, and shows its preference for carbon monoxide by discarding oxygen.

A Study of Stink-damp.

Experiment.

The apparatus and method used for carbon monoxide will be satisfactory. Place in the tube a *small* quantity of iron sulphide and cover with *dilute* sulphuric acid. Show that the gas is combustible, and notice the products of the burning.

Dip a piece of blotting-paper into lead acetate solution, made by dissolving lead acetate in water, and notice the blackening produced by the gas when the paper is held above the mouth of the tube.

This gas has a most offensive smell resembling the odour of rotten eggs, and therefore may easily be detected by the nose. The other simple way of detecting it—by the black colour it produces on a paper soaked in lead acetate solution, or on any silver which you happen to have—is worth noticing. Compare these two easy ways of recognizing stink-damp with the difficulty of detecting fire-damp, which has no smell and no effect on paper dipped into any solution. Stink-damp often occurs in fire-damp in small quantities; if it were always present its detection would be a clue to the presence of fire-damp.

The smell of stink-damp is often noticed when rock or coal is struck by a hammer. This is undoubtedly due to there being small quantities of iron sulphide in the material struck. The occurrence of sulphuretted hydrogen in mine air or iron sulphide in coal, is not very difficult to explain. Vegetable substances contain sulphur, hydrogen, and iron; in their decomposition small quantities of sulphuretted hydrogen and iron sulphide may be formed. The same may be said of some animal substances, e.g. eggs.

Experience.

You have probably noticed a silver spoon will blacken when used in eating an egg, and that an oil painting darkens with age. In each case it is stink-damp; in the egg coming from the yolk, and in the case of the picture coming from the house gas.

The well-known smell of decomposing cabbage, or greens of any kind, is often due to the presence of sulphuretted hydrogen.

Stink-damp is also found in the gas evolved from gob fires and in the blasting of powders.

It is a gas that very easily ignites; a temperature half of that necessary for igniting hydrogen gas, marsh gas, and carbon monoxide is sufficient. Small quantities of this gas will quickly produce giddiness and vomiting, and finally death. It is five times more poisonous than carbon monoxide.

Iron sulphide often reveals its presence in coal by exploding in the fire-grate and being shot into various parts of the room. In the absence of air, iron sulphide may be formed by sulphur and iron attacking each other. We have seen by the experiment that from iron sulphide sulphuretted hydrogen can be obtained.

The foregoing helps to show how this gas may arise in the decomposition of that very much altered vegetable material called coal.

The Gas Called Hydrogen.

Hydrogen is a gas which only occurs in mine air in very small quantities; it is produced in blasting operations and is also found in fire-damp in small quantities. Hence it is studied in this chapter although it is not spoken of as a damp.

Explosive Force of Hydrogen.

Fit up a soda-water bottle with a loosely fitting cork and a short glass tube passing through the latter (see Fig. 69). Place into the bottle a small amount of dilute sulphuric acid and zinc. Allow the action to proceed for half a minute, then wrap up the bottle in a duster and apply a light to the tube, or bring up the bottle in the position shown to a burner.

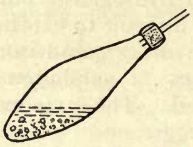

FIG. 69.—Bottle ready for wrapping up in a duster.

It is a colourless gas, violently explosive; when being liberated from sulphuric acid by the metal zinc the bubbles are easily seen rising up through the liquid.

Hydrogen occurs in coal gas to the extent of about 50 per cent, and as there is a large quantity of marsh gas in it one may expect coal gas to be very explosive.

Hydrogen is not of much importance to the miner, but a knowledge of it is necessary on account of its being a constituent of marsh gas and sulphuretted hydrogen. The latter is hydrogen which having taken up, or fixed, some sulphur is therefore called sulphuretted hydrogen. Sulphurized rubber is similarly made from rubber and sulphur. Marsh gas is sometimes called carburetted hydrogen because its constituents are carbon and hydrogen.

Hydrogen is the lightest of all substances, and so if its heaviness is represented by one, it follows the heaviness of all other gases must be represented by a bigger figure. We may therefore write down a few important gases as an illustration:—

Hydrogen . .	1	Marsh gas . . .	8
Nitrogen . .	14	Carbon monoxide . .	14
Oxygen . .	16	Carbon dioxide . .	22
Air . . .	14·4	Sulphuretted hydrogen .	17

The table tells us how much heavier than hydrogen is an equal bulk of any of the gases mentioned.

After-damp.

This word refers to the gases of the mine after an explosion has occurred in which fire-damp or coal-dust, or both, have taken part. We have learnt that when marsh gas is burnt it produces carbon dioxide and water vapour, hence we should expect to find these two substances in after-damp. We have learnt also that when coal burns in plenty of air it forms carbon dioxide, a deficit of air makes carbon monoxide liable to be produced; hence we may expect to find both these gases present in the mine after an explosion. Nitrogen will not burn, i.e. it cannot be used up in an explosion and so will remain in the air untouched; but unfortunately nitrogen does not help the life of a living thing.

The after-damp of the Usworth Colliery Explosion of 1888 had the following composition:—

Carbon dioxide . .	4·54 per cent.
Carbon monoxide . .	2·48 „
Methane . . .	8·68 „
Oxygen	7·23 „
Nitrogen . . .	76·80 „
Impurities . . .	·27 „
	100·00

After-damp may or may not support the burning of a candle; this depends upon the amount of air present. It is sure to be dangerous to human beings on account of the presence in it of carbon monoxide.

Black-damp.

This gas will extinguish a light and will not burn. Up to the present we have met two gases which behave in the same way as black-damp; they are carbon dioxide and nitrogen. The question arises, is black-damp a different gas from these two or is it a mixture of them, or only one of them? It was originally thought that black-damp consisted of carbon dioxide, but it is now known, if unmixed with air, to consist of carbon dioxide and nitrogen. The

proportion of the two gases vary in different samples of black-damp, and if we leave out of consideration any air mixed with them, then the following figures show that there is always much nitrogen present :—

Nitrogen varies between 88 to 85 per cent.
Carbon dioxide varies between 12 to 15 per cent.

Suppose we took a sample of pure air and by burning carbon in it turned all the oxygen into carbon dioxide; then we should have a specimen of pure black-damp of the following composition :—

Nitrogen	79 per cent.
Carbon dioxide	21 ,,

If we left in 10 per cent of oxygen, then the black-damp would have 50 per cent of air in it, and its composition would be :—

Air	50 per cent.
Carbon dioxide	11 ,,
Nitrogen	39 ,,

You will see how these figures are arrived at after reading the following paragraph.

Ways of Stating the Composition of Damps.

The manner of stating the composition of the damps which are mixtures of different gases is worth considering. In this connexion it should be recalled that fresh air contains oxygen and nitrogen in the proportions of four of nitrogen to one of oxygen; more accurately it is 79 of the former to 21 of the latter, but the simpler numbers will be exact enough. It is therefore plain that if we multiply the amount of oxygen in a gas by 4 the result will give the amount of nitrogen, and by addition of the oxygen and nitrogen we have the quantity of air present in the damp, or gas mixture.

In illustration of this we will give the composition of a gas mixture from a freshly hewn sample of coal.

Carbon dioxide	1·6	per cent.
Methane	44·6	„
Nitrogen	44·7	„
Oxygen	8·8	„
Other gases	·3	„
	100·0	„

The oxygen and nitrogen form a certain quantity of air, and so the composition may be written as follows:—

Carbon dioxide	1·6	per cent.
Methane	44·6	„
Nitrogen	9·5	„
Air	44·0	„
Other gases	·3	„
	100·0	„

The 44 per cent of air is obtained in this way: 8·8 × 4 = 35·2 per cent of nitrogen, and then the 8·8 per cent of oxygen added. This leaves 9·5 per cent of nitrogen in excess, i.e. above the amount in the 44 per cent of air.

The analysis of the air from a return airway was stated in the following figures:—

Fire-damp	·5	per cent.
Oxygen	19·5	„
Carbon dioxide	·75	„
Nitrogen	79·25	„

This analysis does not in a plain manner tell us the amount of air present, it may be calculated in the manner described: 19·5 × 4 = 78 per cent, the nitrogen corresponding to the 19·5 of oxygen, and so the air is 97·5 per cent, i.e. almost pure air. The composition may therefore be written:—

Fire-damp	·5	per cent.
Air	97·5	„
Nitrogen	1·25	„
Carbon dioxide	·75	„

It is a far more instructive way and has more meaning than the first one.

As black-damp consists of carbon dioxide and nitrogen the analysis might be written thus:—

Fire-damp	·5	per cent.
Air	97·5	,,
Black-damp	2·0	,,

In this case the name fire-damp means methane, and not in the sense used in the analyses on page 107.

The composition of the sample of after-damp of the Usworth Colliery explosion has a more impressive tale to tell if we write it as follows:—

Air	*36·15*	per cent.
Black-damp	*52·42*	,,
Carbon monoxide	2·48	,,
Methane	8·68	,,
Impurities	·27	,,

The air and black-damp are calculated as shown on pages 120 and 121.

Practical Application to Mining.

Fire-damp, called by the miner "gas," is usually given off steadily from the coal as it is worked, but sometimes an accumulation is tapped and the gas issues forth in the form of a "blower".

In the early days of mining, when pits were shallow, the fire-damp found its way, through cracks in the rocks, to the surface and was seldom found in the workings of the mine. As the top seams became exhausted and pits became deeper it was confined in the mine, and its presence was, and is to-day, a source of danger to the miner.

Before the introduction of the safety lamp the methods of testing for and removing fire-damp were very primitive. In order to clear the workings of fire-damp, the "fireman," wrapped in old clothing saturated with water and carrying a lighted taper fixed to the end of a long stick, travelled round the mine and removed the gas by igniting it with his taper. Another method was to hang a naked light in a

place where gas was given off, and by burning it up prevent its accumulation.

Fire-damp is detected by the "cap" or halo which is formed round the flame of the candle or lamp. The cap is best seen on the lowered and non-luminous flame of the safety lamp. When candles were used the observer who

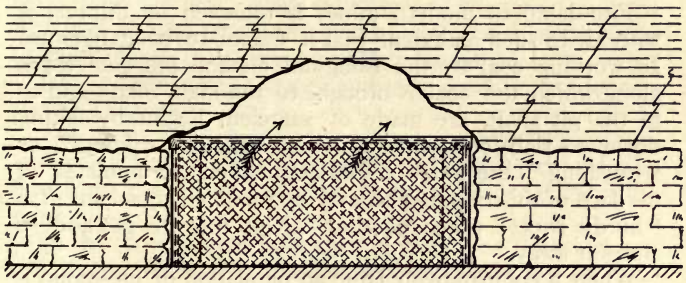

FIG. 70.—Hurdle sheet—front view.

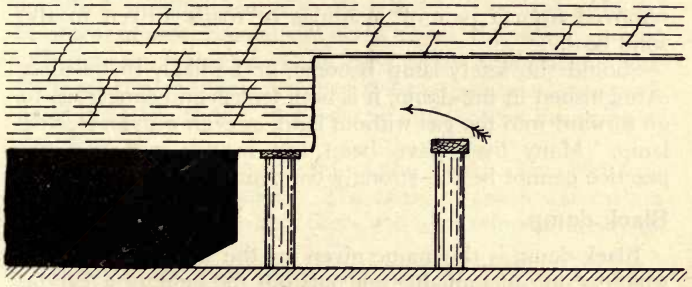

FIG. 71.—Hurdle sheet—side view.

wished to test for gas had to place his hand in front of the flame in order that its brightness should not prevent him seeing the cap.

The fire-damp cap is caused by the burning of the particles of gas in the immediate neighbourhood of the flame. When the amount of gas in the air is small the particles are a long way apart, and the cap is very faint and not easily seen; but

as the proportion of gas increases the cap becomes larger and more clearly defined. If the proportion of gas continues to increase the particles become so close together that if combustion is once started each particle will ignite its neighbour, and combustion will travel through the mixture of air and gas without any further help from the initial source of heat. This is called explosion.

Fire damp in modern mines is removed by diluting it with air to such an extent that it ceases to be dangerous. In working coal by the Longwall method the gate roads along which the coal is brought to the main roads and so to the pit shaft, are made of sufficient height by taking down a slab of roof. This is called "ripping" or "brushing" the gate. Fire-damp often accumulates at the face of this ripping and may be removed by means of a "hurdle sheet" which conducts air up into the gas and so clears it away.

When a comparatively large accumulation of fire-damp is found, it should be removed in layers or slices as shown in Fig. 37, Chapter III, page 62, which shows how the gas is removed from a pair of headings or roads driven in the solid coal.

Should the safety lamp become, or be likely to become, extinguished in fire-damp, it is both foolish and dangerous to go forward into the gas without light, or even with an electric lamp. Many lives have been lost in this way and the practice cannot be too strongly condemned.

Black-damp.

Black-damp is the name given by the miner to the gas which is not inflammable but puts out the light of a candle or lamp. It accumulates in old workings, and when a fall of the barometer takes place may come out into the roadways where work is being carried on.

When mixed with air it is detected by its effect on the flame of a candle or lamp, which burns dimly or is extinguished according to the proportion of gas present.

Carbon dioxide in air has a similar effect on the flame, and the miner would probably be unable to determine by this test which gas was present.

It is, however, important to notice that while carbon dioxide is considerably heavier than air and likely to collect in low-lying places, black-damp may be very little heavier than air, and even lighter.

White-damp.

White-damp or carbon monoxide is formed in mines when shots are fired, when explosions of fire-damp or coal-dust and air take place, and may be given off from fires due to spontaneous combustion or other causes.

It is a very poisonous gas, and very small proportions in air are dangerous.

The need for a knowledge of its properties, behaviour, and effect on men may be better realized by considering how some lives have been lost owing to its presence in the mine.

In the report of the Inspector of Mines for Yorkshire and the North Midlands, 1910, an account is given of an accident in the sinking at Thorne Colliery, near Doncaster.

A round of fifteen shots, each containing 1¼ lb. of gelignite, was fired simultaneously by electricity. The men returned to work almost immediately—in about six minutes—and although no fumes or smoke were visible some of the men were affected and felt ill; they did not however leave work until the end of the shift—three hours after the firing of the shots.

On reaching home several of the men became seriously ill and one of them died. The cause of death was carbon monoxide poisoning, and there was also some irritation by nitrous fumes.

Another accident, which occurred at Langton Colliery, Nottinghamshire, is described in the same report.

A very small heading was being driven to make communication with another road. The deputy fired a charge of Rippite and afterwards examined the place. He detected no danger, and a skilled miner went to work in the place alone. About fifteen minutes after he was found lying dead near the face. He had died from carbon monoxide poisoning, and probably had fainted before he realized that he was in danger.

It is very difficult to detect the presence of carbon monoxide, as even dangerous quantities have no appreciable effect on the flame of a safety lamp. The only practical method of detection which has been successfully employed is the use of mice or small birds as detectors. They succumb to the poison much more quickly than a man does, and by observing their symptoms it is possible to determine the presence of dangerous quantities of the gas in time to make a safe retreat.

Dr. Harger has recently given an account [1] of a method of detecting carbon monoxide by the reduction of iodine pentoxide—a chemical method. The heat necessary to start the reaction—about 170° Centigrade—is found in the safety lamp between the top of the gauze and the bonnet.

The following requirements of the Coal Mines Act relating to gases are very important:—

"A working place must be considered dangerous if the percentage of inflammable gas in the general body of air is found to be 2½ per cent or upwards, or if in a part of a mine worked with naked lights, 1¼ per cent.

"If a workman discovers the presence of inflammable gas in his working place, he shall immediately withdraw therefrom and inform the deputy.

"Two or more small birds or mice for testing for carbon monoxide shall be provided and maintained at every mine which maintains a rescue brigade or brigades."

QUESTIONS.

1. In 1914 there were explosions of marsh gas in several houses at Bradford, and in the report it stated, "the gas was attracted by open fires" in grates. Can you offer any other explanation of the gas moving towards the fire-grates?

2. A sample of air from the return airway of a pit gave the following results on analysis:—

Pure air	90·5 per cent.
Black-damp	9·0 „
Fire-damp	·5 „

Write down the names of the gases present.

3. Arrange the gases found in mines in two groups: (1) combustible; (2) non-combustible.

[1] "Trans. Inst. Mng. Eng.," Vol. XLVII.

4. A match may be ignited in the air without exploding or setting it on fire. What does this prove about the air and the gases composing it?

5. Name the gases of the mine which have a smell. What are the advantages of a gas possessing a smell?

6. Which gas is most likely to be ignited in a mine by a spark? How are sparks likely to be produced?

7. Mention the gases found in the mine which are (1) necessary for health and life; (2) injurious to health and life. Are any of these gases found in an ordinary living-room?

8. What gas is added to the air by breathing? How is the same gas produced in a mine?

9. What is the difference between black-damp and choke-damp? How could you prove by experiment they are different gases?

10. Are there any gases present in coal gas which are not found in a mine? If so, mention them.

11. On page 136 it is said a mixture of air and coal gas, containing 6·5 per cent or less of the latter, will not burn. Yet "gas caps" are often shown containing less than 6·5 per cent of coal gas. Can you reconcile these two facts?

12. How has it been proved that black-damp contains carbon dioxide?

13. Distinguish between marsh gas and fire-damp. If some marsh gas escaped into the air would you call the mixture fire-damp?

14. Can you give reasons why the various damps have one of the following prefixes: black, white, choke, after, fire, and stink?

15. What conditions decide that miners should be withdrawn from their working place? What should be done when they have withdrawn?

16. Burnt and injured people are not a very large proportion of the killed in colliery explosions; how do you account for the large proportion otherwise killed?

CHAPTER VII.

SUBSTANCES WHICH, MIXED WITH AIR, FORM EXPLOSIVE MIXTURES.

EXPLOSIONS are fairly well known to everybody, but it is not as well known that air must get mixed with the gas or vapour causing the explosion before one is possible.

Recall any information you possess on colliery explosions; on gas explosions in houses; on explosions due to liquids giving off inflammable vapours; on explosions used as the driving force, in the engine of a motor-car, or motor-cycle or any engine driven by gas, petrol, or oil.

The effects of well-known explosions are better known than their causes; shattering walls and demolishing buildings are the common accompaniment of "good" explosions. Small explosions or "bangs" are known to most people who have experience of any form of atmospheric burner. These explosions, due to mixtures of air and gas, or vapour, must not be confused with those occurring in the use of explosives, which are generally solid substances capable of exploding independently of the presence of air, e.g. bombs dropped from aeroplanes.

Experience.

The gas-stove burner, the incandescent gas burner, ring-stove burners used in workshops, are all examples of atmospheric burners: those where gas and air mix. If there be any burners of the foregoing type in your school or home search for the gas nipple, and note close by it is an inlet for air. The gas leaving the nipple rushes up a tube leading to the burner and the air follows; as they go along it they mix.

In each case we may know by experience that in lighting such burners there are "pops" or explosions in the tube, and

the gas at the nipple is found to be burning. This is the commonest and least dangerous kind of explosion ; it shatters nothing because the exploding gas is not shut up, but its exploding force disturbs the atmosphere, and in so doing makes a sound.

It is important to notice that petrol, gas, and oil may all burn silently as a flame when giving light. This is because particles of the flame keep well together and are not mixed with air. Where gas particles are not mixed with air each particle of the gas or vapour has to wait its turn until it gets on the edge or on the faces of the flame so as to get air to burn it ; i.e. to take all the light and heat-giving power out of it. As soon as the particles of a gas or vapour get intimately mixed with air, in a closed space, there is a greater chance of an explosion.

Experiment.

Take two pellets of cotton-wool and soak each with ether, or petrol, or benzoline. Place one piece in a porcelain dish and the other in a glass cylinder. Shake the one in the cylinder so as to mix the vapour and air ; have a glass cover on the cylinder. Apply a light to each, in the latter case with caution.

Compare and explain the burning of the ether in each case.

The porcelain dish is a very open vessel and the burning will be ordinary combustion, but in the glass cylinder there may be a slight " pop " on applying the light. The vapour in the cylinder is more confined than any given off in the porcelain dish, and this, taken in conjunction with its firing instantaneously, gives a small explosion. Confining a combustible vapour mixed with air makes it dangerous when a light is applied. The following experiment will give a better illustration of the effects of firing a vapour in a less open vessel.

Experiment.

Take a flask, or a bottle, or other vessel with a neck, and place C in it a drop or two of petrol or ether. Warm the liquid slightly for vaporizing it. Drop a lighted match into the mixture of vapour and air, notice the explosion. If one or two drops fail try a few more drops, but increase by one at a time.

This experiment brings us in contact with the fact that petrol and air will explode when ignited, and the "pop" obtained in the experiment tells us that gases are forced up the neck of the vessel. A valve on the top of the neck could be lifted up; it would fall down after explosion. Such an idea brings us face to face with using petrol and air as a motive power.

The fact that petrol and air easily form an explosive mixture has led to the making of the petrol engine. The explosion of the mixture in that part of the engine called the cylinder—the envelope or jacket in which the piston moves—leads to the forcing of the piston along and finally the turning of the wheels.

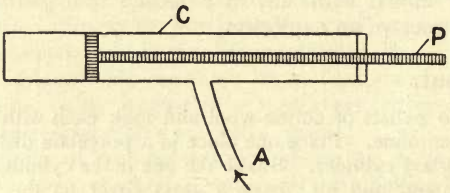

FIG. 72.—Diagram of the cylinder of an engine.

The movable piston-rod is shown at P; it works inside the cylinder C. The gas and air intake is shown at A. The principle is the same in the gas engine and petrol motor. An explosive mixture of either gas, or petrol vapour, and air is injected or sucked into the cylinder along A, and exploded usually by an electric spark. The explosion, which is very rapid combustion, results in the cylinder being filled with gases at a high temperature, and the piston is driven forward. Then the piston returns and the gases are expelled from the cylinder. This occurs very frequently, so the engine is set working, the wheels turned, and the car propelled. The maximum force is got with a mixture consisting of—

2·6 parts of petrol vapour.
97·4 „ „ air.

Above 2·6 parts of petrol vapour, and therefore a decrease in the parts of air, the force of the explosion diminishes; when it has become 5 parts of petrol vapour and 95 parts of air it

burns quietly. It is therefore important in such engines that the correct proportions of air and petrol vapour should be mixed.

One gallon of petrol makes 1500 cubic feet of mixed air and petrol vapour.

Notice that on these explosions taking place in a cylinder there is a *movable* piston which takes the force of the explosion; if it were a fixed thing, then the force would be felt all over the cylinder and a shattering of its walls might occur.

Experience.

If a bottle of benzoline (or benzine) is bought from the chemist's it will be labelled "Highly Inflammable," and further the label will tell you not to bring a light near nor to use it too near a fire.

Why? The boiling-point of Benzoline lies between 70° C. and 90° C.; it is therefore a very low one, and inflammable vapour is easily given off. If air got access to the bottle a mixture of air and benzoline vapour would be formed; then a light would explode the mixture, scattering the bottle liquid, and probably burning the holder. Benzoline is a near relative of petrol and petroleum; the latter is the parent substance of both.

All inflammable liquids such as petrol, gasoline, petroleum spirit, benzoline, etc., have to be handled very carefully, as at the ordinary temperature of the air they give off inflammable vapours. If a light be brought near it may cause their vapour to ignite; this danger is warded against by the special precautions taken by dealers and railway companies in the storage and transit of these liquids. In no circumstances is a naked light to be allowed in the store-rooms, or to approach the storage tanks situate in the open air.

The most volatile relative of petrol called gasoline, which boils between 50° C. and 60° C., would be extremely explosive if mixed with air and a light applied.

The easier a substance becomes a vapour and mixes with air the more dangerous it is owing to the possibility of explosions being produced.

If we arrange the four mentioned liquids according to the lightness of their vapours, the following table is got :—

	Boiling-points.
Gasoline (lightest) . . .	50°-60° C.
Benzoline or benzine . .	70°-90° C.
Petrol	90°-130° C.
Petroleum (heaviest) . .	150°-300° C.

and we at once perceive from our experience and knowledge of these liquids that the lightest vapour belongs to the liquid with the lowest boiling-point. The lighter the vapour the more rapidly its particles mix with air and the more likely an explosion may result if it be an inflammable vapour. All the foregoing substances are obtained from the natural mixture called crude petroleum after it has been brought from the oil wells. It is, when first obtained, a thick syrupy liquid, in appearance not unlike the coarsest kind of treacle, varying in colour from brown to nearly black ; it has a rather unpleasant odour.

This crude petroleum is refined as coarse treacle is, that is, separated into different parts ; four of these parts we have already considered.

Gases in Crude Petroleum.

It is a fact that there are substances in crude petroleum with lower boiling-points than those we have considered ; these are gases ; the temperature of the air keeps them so because its temperature is too high to allow them to become liquids. There are gases in American crude petroleum which come out of the oil in much the same way as carbonic acid gas comes out of an effervescing drink. These gases, one of which is marsh gas or fire-damp, are artificially liquefied by cold and pressure and sold for industrial purposes, such as lighting, where there is no other gas supply possible.

Solid Substances in Petroleum.

Vaseline and paraffin wax are two substances which belong to the petroleum family : crude petroleum is their parent. It may be remarked that these two substances are not ex-

plosive, which is true, and the reason is not far to seek. They are solid or semi-solid substances whose boiling and melting-points are so far above the ordinary temperature of the air that they do not even give off any vapour. There is therefore no chance for a mixture of vapour and air to be formed. If either be highly heated so as to be vaporized the vapour which comes off is combustible.

In separating the various constituents of petroleum from one another heat is employed, and those substances which are naturally gases easily leave the liquid; then those substances which are naturally liquids boil away, the two substances, vaseline and paraffin, being left behind. The use of heat in the separation of the petroleum chars part of the constituents, and this is left behind in the vessel as coke; it is used for making electric light carbons.

A Further Note on Petroleum.

The first discovery of petroleum in quantity was made in a disused mine in Derbyshire in 1847 as a spring of the oil. This spring is now exhausted.

In 1848 the oil began to be made artificially by heating and distilling cannel coal.

In 1861 petroleum was found in Pennsylvania in a well artificially bored, the well giving at least 100,000 gallons a day. Since the foregoing date petroleum has been found in different parts of the world.

Now it is important to notice that these sources are either intimately connected with the under parts of the earth's surface, or with coal. It appears then that as well as the earth providing us with a solid combustible material called coal which comes from various depths and gives off inflammable gas, it also provides us with a combustible liquid called petroleum. Both give off the same inflammable gas known as marsh gas or fire-damp. Moreover, the making of petroleum from cannel coal, helps to show how related coal and petroleum are, and the presence of fire-damp in both helps to further emphasize the relationship.

If then we keep before our minds the inflammability and the ease with which some of the constituents of petroleum

explode, we shall recognize the danger of explosion from the gases which come out of coal.

Some Simple Explosions.

Experiment.

Make a V-shaped cardboard trough about 18 inches long and fix one end of it higher than the other; at the lower end place a lighted candle. From the higher end pour the *vapour* of ether or petrol down the trough; this is conveniently done by placing a small quantity of the liquid in a beaker; it vaporizes and flows as a liquid would down the trough. C

It is an advantage to perform the experiment in a place free from strong draughts.

This experiment illustrates "striking back," i.e. the passage of a flame backwards to the source of supply. The vapour flows down the trough and mixes with air; the mixture thus formed touches the light of the candle and the flame of the burning ether runs up the trough to the beaker, igniting the ether in it. This is one reason why there should be very little ether in the beaker. The rate at which the flame travels up the trough should be noted; it is practically instantaneous.

If gas from a blow-hole had been filling a roadway in a mine and becoming mixed with air, and if a light were applied to it or the mixture flowed towards a light at the end far away from the blow-hole, the flame would strike back to the blow-hole and light the issuing gas.

Experience.

You have no doubt lit a gas by holding a match several inches away from the issuing gas. The mixture near the lighted match takes fire and then the flame strikes down to the gas nipple.

The Bunsen Burner and a Mixture of Gas and Air.

Passing up the tube of the Bunsen Burner when the holes are open is a mixture of coal gas and air; at the top it burns very quietly when lighted. Yet we know that if there is any escape of gas in a room, which of course mixes with the air of the room, generally the introduction of a light leads to a more or less violent explosion.

Experiment.

Turn down a lighted Bunsen gently so as to produce a small flame and see if the flame strikes back to the gas nipple. By altering the "air intake" when a full flame is burning, a point is reached when the flame makes a faint roar. "Striking back" and "roaring" both illustrate explosions.

Roaring consists of a succession of very faint "pops" due to alteration of the air supply. The place where "roaring" occurs is where the flame and inner cone of mixed air and gas come together, it may be easily seen as a troubled region in the flame. Diminishing the air supply makes the mixture richer in coal gas, and some of this mixture arrives at the hot inner surface of flame, ignites and "pops".

The "striking back" of the Bunsen flame is well worth noticing, because it is similar to the propagation of an explosion. As the burner is turned down the speed of the gas rushing up the tube is checked, and as the flame is kept at the top of the tube by the speed of the uprushing mixture of gas and air, an opportunity is afforded to the flame to travel through the mixture of air and gas in the tube and so explode it. The flame of the explosion ignites the gas issuing from the gas jet at the bottom of the tube.

Experiment.

Take a gas cylinder and trough of water and fill the cylinder with the following parts of coal gas and air:—

(1) $\frac{1}{3}$ and $\frac{2}{3}$.
(2) $\frac{1}{12}$ and $\frac{11}{12}$.
(3) 1 and 6.

The divisions of the cylinder may be made with gum paper.

The cylinder must be filled with water and the gas tube held under its mouth for collecting the gas; it will be necessary to have the open end of the gas tube only an inch or so below the water surface in the trough for the gas to flow out. Withdraw the gas tube from under the cylinder when the latter has filled to the required amount. Air may then be let carefully in by bringing the mouth of the cylinder slowly through the water surface.

Apply a light to each cylinder. Notice if (1) burns quietly, (2) with difficulty, (3) with explosive effects, the flame travelling slowly down the jar.

The composition of the mixtures of gas and air can easily be put as percentages by stating the amounts as parts of a hundred, i.e. the number of cubic inches or feet of each in 100 cubic inches or feet of the mixture.

The proportions of gas and air stated as percentages are respectively: (1) $33\frac{1}{3}$ and $66\frac{2}{3}$; (2) $8\frac{1}{3}$ and $91\frac{2}{3}$; (3) $14\frac{2}{7}$ and $85\frac{5}{7}$. Compare these and the results obtained in the experiments, with the following statements.

The following mixtures will behave as stated:—

Mixture.	Will not Burn.	Burns Gently.
Coal gas . .	6·5	25
Air . . .	93·5	75
	100·0	100

An amount of gas represented by any number between 6·5 and 25 mixed with air will explode more or less violently, e.g. the following mixture:—

Coal gas	14·3
Air .	85·7
	100·0

This percentage as a matter of fact gives the most violent explosion. Less than 6·5 will not burn, more than 25 burns gently.

These experiments on the difference in the behaviour of mixtures of air and coal gas bring out the fact that all mixtures of coal gas and air will not explode; their exploding depends upon the amounts of air and coal gas mixed together.

The figures and facts should help us to explain how it is that explosions produced in houses by the searching for a gas escape with a light differ in their effects. Various proportions of gas and air behave in different ways, and so the searcher may either be lucky or unlucky enough to find a gently burning, an explosive, or a non-burning mixture.

Compare the foregoing figures and facts with those given on p. 107, on mixtures of air and marsh gas.

The foregoing experiments and facts show that great dilution of an inflammable gas with air destroys the power of inflammability of coal gas or marsh gas. Therefore, in mines dilution with air may tend to diminish the chances of an explosion, and dilution with a flowing current of air will result in clearing out objectionable gases which are not inflammable and yet very injurious to human beings.

Dilution.

Dilution of a liquid is very well known, and is often performed on account of its being too strong for any particular purpose. The dilution is generally done by adding water, owing to its not having that particular property of the liquid which undergoes dilution.

Water is widely used for diluting and carrying away purposes in public drains; it is here a cleansing current. It is very much the same as the cleansing effect of a river in flood, which sweeps forward all the ill-smelling deposits formed on its banks and dilutes the objectionable liquids poured into it by streams from manufacturing districts.

Experience.

Too strong tea is diluted by hot water, or too sweet a liquid by the addition of an unsweetened liquid. Too strong a tobacco is diluted by its being mixed with a mild kind.

A stuffy hall, room, or railway carriage has its ventilators opened to dilute the foul inside air.

The foregoing therefore shows dilution applied to liquids, solids, and gases; it is performed to tone down some objectionable feature of a substance.

Experiment.

Take a porcelain dish and place in it a spoonful of methylated spirit, ignite it and then put out the flame by covering the dish. Add a spoonful of water to the spirit, stir, and try to ignite ; if it ignites add further small quantities until it ceases to ignite.

The power of inflammability is gradually toned down and finally destroyed.

The passage of large volumes of air through the pit

dilutes all the obnoxious, injurious, and inflammable gases produced or found therein, and after their dilution the ventilating current carries them out of the mine. Where parts of the ventilating current are moving slowly, as at the coal-face, the health-destroying gases and explosion-producing ones are mixing with it and become so dilute that their power for evil is much diminished if not actually destroyed.

Dilution should be brought about as soon as you find there is an escape of gas in your house ; open all doors and windows so that air can come in, dilute it, and carry it out for further dilution in the atmosphere. In the room as in the pit the first step is to dilute an objectionable gas or gases, but the healthiest way is to clear it out completely.

Practical Application to Mining.

Probably the first recorded colliery explosion occurred early in the seventeenth century and caused the death of one man.

Since that time explosions have been many and the number of lives lost from this cause has been very great indeed.

The majority of colliery explosions are small ones, causing the loss of few lives individually but mounting up to large numbers in the aggregate.

Occasionally a disaster of great magnitude occurs such as the Sengenydd explosion, which took place on 14 October, 1913, and in which 440 men lost their lives.

The average death rate from explosions of fire-damp and coal dust in all mines under the Coal and Metalliferous Mines Regulation Acts, during the ten years from 1902 to 1911, was ·165 per 1000 persons employed.

In 1913 the number of deaths from colliery explosions in mines under the Coal Mines Regulations Act was 462, and the number of persons injured 150.

Colliery explosions may be divided into two classes :—

1. Purely fire-damp explosions, which are usually limited in extent and cause comparatively little damage.

The Whitehaven Colliery explosion of 1882 is perhaps

the most considerable explosion of fire-damp and air recorded in this country.

It was estimated that the quantity of mixture exploded amounted to about 32,800 cubic feet, yet the damage done was not great and the force of the explosion did not extend far beyond the district in which it occurred.

2. Explosions in which coal dust takes part. These often travel great distances, causing enormous damage and the loss of many lives.

It was not until early in the nineteenth century that coal dust was suspected of having any influence on colliery explosions, but since then a great many experiments have been made with a view to finding out the magnitude of the part played by coal dust.

In 1908-9 the British Coal Dust Experiments, conducted by the committee appointed by the Mining Association of Great Britain, were carried out at Altofts, Yorkshire. The experimental gallery was designed to resemble as far as possible the conditions of the mine. It consisted of an "intake" and "return". The intake was 7 feet 6 inches in diameter with a concreted roadway along which ran a line of rails. The return was 6 feet in diameter and zig-zag in form.

A quantity of 50,000 cubic feet of air per minute passed along the gallery during an experiment. The quantity of coal dust employed was 1 lb. per linear foot, or 0·4 oz. per cubic foot of air space. The dust was usually ignited by firing a charge of 24 oz. of blasting powder from an iron cannon of 2-inch bore, stemmed with 8 inches of dry clay.

These experiments definitely established the fact that coal dust, in the complete absence of fire-damp, is explosive when raised as a cloud in air and ignited.

Cause and Prevention of Explosions.

Many explosions have been caused by naked lights, defective lamps, and shot firing, but other causes, such as the sparking of electrical machinery and electric bells are on record. Coal-dust explosions may be initiated by a blown-out

shot, or a comparatively small explosion of fire-damp may develop into a dust explosion on a large scale.

Many explosions have been caused by ignorance or carelessness on the part of workmen, and there appears little doubt that if the regulations laid down in the Coal Mines Act were thoroughly understood and carried out, the number of explosions would be greatly reduced. A few extracts from inspectors' reports may help to make this clear.

"On a Sunday night the three deceased men, before entering the safety lamp area, voluntarily gave up matches and cigarettes to the fireman of the section, who did not for this reason search them as he should have done. They proceeded to their level working-place, but left it at once and went to work in the rising place of a neighbour who was absent, and to which they had no right to go, and in which the fireman had told them gas had accumulated and was present.

". . . They were working with C.E.A.G. electric lamps, and in spite of the fact that they had been told of gas, they had secreted matches and cigarettes in the folds of their caps and had begun to smoke, as burnt cigarettes and matches were afterwards found in the working face, with the result that the accumulation of gas was ignited and an explosion occurred, and so seriously burned them all that they died shortly afterwards."

"A collier was burnt by the ignition of fire-damp by his naked light on going into a place which was fenced off, in order to get a boring machine."

"A fireman was burnt by an ignition of fire-damp ignited by a match which he struck to relight a safety lamp."

The danger from coal dust may be reduced by using dust-proof tubs, and so preventing to some extent the deposition of dust; by removing the screens a considerable distance from the shaft, or so collecting the dust made at the screens that it is prevented from going down the shaft; by cleaning up and preventing accumulations of dust in haulage roads, and by the application of water or incombustible dust.

In the Fifth Report of the Explosions in Mines Committee it is stated that a 1 to 1 mixture of coal dust and incombustible dust could not be fired by a charge of 24 oz. of blasting powder fired from a stemmed cannon in a 7 feet 6 inches dia-

meter gallery, when the atmosphere contained no combustible gas.

The following requirements of the Coal Mines Act are very important :—

In every mine, unless the floor, roof, and sides are naturally wet, arrangements must be made to prevent as far as practicable, coal dust from the screens entering the downcast shaft.

Tubs shall be so constructed and maintained so as to prevent coal dust escaping through the sides, ends, or floor of the tub.

The floor, roof, and sides of the roads shall be systematically cleared so as to prevent coal dust accumulating.

Such systematic steps either by way of watering or otherwise, as may be laid down by the regulations of the mine, shall be taken to prevent explosions of coal dust occurring or being carried along the roads.

QUESTIONS.

1. What would be the effect of dropping a lighted match through a small hole into the "gasometer" of a town?

2. Steam is issuing in large quantities out of a large waste pipe and mixes with air. What would be the effect of introducing a light into the mixture?

3. A room is believed to be full of air and gas, due to a gas escape. Which will be the safer way to go into it: (1) using a lighted candle; (2) using a safety lamp?

4. Pick out from the following mixtures of gases those which are explosive :—

Carbon monoxide and air.	Carbon dioxide and coal gas.
Carbon dioxide and air.	Bunsen gas and air.
Methane and nitrogen.	Methane and air.

5. Give a sketch of any apparatus you know which burns coal gas and air. Which part of the air and coal gas is left unburnt when there is a flame? Do you think the incombustible part helps to damp down explosive effects?

6. What would be the effect of lowering a lighted lamp into a chimney when in use? Give reasons for your answer.

7. A flash of lightning cuts through the air and forces it apart, then the two parts bang against each other, producing thunder. Would you call this an explosion? Does it resemble one in any way?

8. Do you think it is safe to take the following liquids down a mine: Petrol, ether, petroleum? Are any used down the pit?

9. What precautions are observed in storing, at the pit-head, lamp

oil? Do you think it does, or does not matter, if oil is carelessly left on the outside of your lamp when you take it down the mine?

10. What dangers are there from smoking in the pit? Supposing a tobacco could be made which would smoke at the same temperature as your body, would it be dangerous to smoke it in the mine?

11. What might happen to a mixture of explosive gases from a spark caused by (1) a pick striking a piece of coal; (2) a nail in your boot kicking a tram rail?

CHAPTER VIII.

FLAMES: THEIR SHAPES AND PARTS.

It is part of the experience of most of us to have heard gas rushing out of a gas jet; although invisible to us gas always betrays its existence by its smell. Nevertheless when the gas is lighted the smell disappears and in burning gas becomes a very visible thing.

The two very distinct yellow and blue parts of the flame denote other changes going on in the gas as it burns. A gas flame has a well-defined shape, but there is no doubt that unburnt gas escaping through the same jet will not have the same shape, the shape of the flame is therefore influenced by its burning. The rush of gas through a burner of any type influences the shape of the flame; we know very well that the tap has often to be used as its regulator. A flaring flame has too much gas passing and the top of the flame will smoke; it has cooled down too much for thorough combustion.

Experiment.

Turn on a gas jet, or burner of any type, and try to light the issuing gas by carefully moving up, or down, towards the source of gas a lighted match or candle. The issuing gas might be explored all round in this way, turning it out at each ignition, to find places where it ignites. It will be very evident if the places are noted that escaping unburnt gas has a very different shape from that of the flame.

The oil lamp flame of the miner bears a great resemblance to the flame produced by the ordinary gas jets, and therefore a study of these flames will be interesting.

Experiment.

Examine the gas pendants in the room for gas burners producing bat's-wing or fish-tail flames. If there are no such

Fish-tail burner. Bat's-wing burner.

FIG. 73.

burners on the pendants obtain one and fix it in the Bunsen tube, light it, and notice the various parts of the flame. Make diagrams showing their parts in your notebook (see Fig. 73).

The slit, or bat's-wing, burner produces a flame in much the same manner as the wick of the miner's lamp, where the wick occupies the slit and brings up the oil supply. In the fish-tail burner the gas issues as two small streams at right angles and striking each other they spread out flat.

All flat flames have an advantage over circular ones; they have a big area from which to pick up the air necessary for good light and complete combustion.

The illuminating power of a good flat flame burner is equal to that of sixteen candles, and so would be described as of 16-candle power. Compare the expression with that used for an engine, e.g. an engine of 16-horse power, which means it can do as much work in a given time as sixteen horses.

Experiment.

Move either the head or the stale end of a match towards the flame and notice if there is a non-luminous outer envelope surrounding the flame. A bit of glass tube or rod shows the envelope by its becoming golden yellow. Notice in the case of a lighted candle the position of the free end of the wick, and what happens to it.

Before the match gets to the yellow part of the flame it will come into contact with an almost invisible coat of highly

heated gas and the head will ignite or the stale blacken. It is important to notice that this happens before the match has reached the yellow part of the flame. This outer invisible coat is spoken of as the mantle; by either word an outer covering is meant. The burning away of the end of the wick takes place in the mantle of the *wax* candle; it is completely changed into invisible gaseous substances which pass into the air. Compare the combustion of the wick of the old-fashioned *tallow* candle; it chars and remains in the middle of the flame, never getting into the mantle; its unburnt black mass has to be snuffed or cut at times.

Experiment.

Place a cool glass rod across the flame of a lamp, candle, or burner, and in the luminous part of it notice the deposition of soot. As the glass rod or tube approaches the flame allow it to stay in the mantle for a short time. The yellow coloration shows the mantle very conspicuously, but there is no black deposit.

The experiment shows that there is an inner portion of the flame that is shielded from the air by the mantle; this inner portion consists of soot or carbon, which being shielded from the air does not immediately get burnt, but by the heat of the flame it gets yellow-hot and so gives the flame its luminosity.

This black substance, technically carbon, and which is momentarily formed in all yellow flames, must come from the substances burning, be it gas, oil, tallow, wax, or coal. Beyond these substances carbon is found in all animal and vegetable products; all in burning show yellow in their flames. What becomes of the carbon in the flame? It gets burnt in the mantle by the help of the air, to an invisible gas called carbon dioxide.

It must be remembered that the material of the flame of one minute is not the material of the next minute. There is a stream of gas particles passing through the pipe and they appear at the gas jet to be changed "in a moment, in the twinkling of an eye," first into visible, yellow-hot carbon, and then into invisible carbon dioxide, and their places are taken by others.

Compare it with a stream of smoke particles passing up a chimney which gives a constant cloud of smoke at the pot. A smoke banner and a flame are different from a flag floating from a mast; the former are composed of different particles every moment of their existences, the flag does not change its particles.

How Invisible Gas becomes Visible Flame.

The yellow part of the flame is that part which gives light and is therefore of importance in mining, just as it is as a scource of lighting in our homes. The same yellow part has to be got rid off when testing for fire-damp.

It is plain that for this yellow part to be produced changes must take place in the gas. Heat is being produced by the burning gas, for the slight heat of the match which turned the *gas* into a *flame* cannot be, and is not, responsible for the large amount of heat the flame produces.

The action of the match on the issuing gas of a burner is very much like setting fire to a train of gunpowder by igniting one end; if we had a very long train we should have a flare lasting for a long time. In either case, gas or powder, a very fierce action starts between oxygen particles and the particles of the lighted body. This leads in the case of the flame to the splitting up of invisible compound particles of the gas, and black particles of carbon are liberated which become yellow-hot by the heat of the flame; thus the flame gets a yellow part.

Experience.

Most people have in making toast burnt the bread, and occasionally may have gone so far as to set it on fire.

This action is very similar to that of the heat of the flame on the original invisible gas. Bread with its white surface is put before the fire and its heat splits up the bread particles, liberating black particles of carbon; these may even burn, as in the gas flame, and finally become carbon dioxide. In either case, then, no carbon particles are visible at first; bread is white and coal gas is invisible, but heat breaks up their particles and so reveals the unseen and hidden carbon

particles. Such actions seem mysterious, but freeing particles from the grasp of other particles reveals them all in their true properties. It is important to remember that all the yellow-hot particles have passed through the blue part of the flame. The size of the blue part may vary in a gas flame according to the quality of the gas; a good quality gas has a large amount of yellow in the flame.

Experiment.

Place a glass rod through the blue part of the flame; no soot will be deposited on it.

The fact that one part is visibly blue again shows that changes have gone on in the original invisible gas; in the blue part action between air and gas is very fierce and there is no chance for black particles to exist in it for even a second of time.

The blue part is what might be called the foundation of the flame, for it forms the base upon which stands the yellow part.

Where there is plenty of air mixing with gas there is no soot but much heat and a blue flame are produced. The same holds in the case of a gas stove; anything placed thereon is not blackened.

The yellow and blue parts are very easily seen and are therefore often regarded as forming the complete flame; we know this is not exact. There is that almost invisible part, the mantle which surrounds the flame, rendered difficult to see by the glare of the yellow part. Stars which shine in the daytime cannot be seen owing to the glare of the sun, and the "cap" on a miner's flame cannot be seen until the flame is turned down low, i.e. the yellow or dazzling part nearly cut out. This explains why it is not easy to see the mantle.

Experiment.

Take an ordinary oil lamp with a flat wick, or a gas pendant with a flat flame burner, light and then turn down the light until there is only a blue band of flame seen. It will only be a very small flame in either case.

This flame is the simplest we can get, its simplicity lies not only in its being of one colour but also in its being a uniform mixture of air and gas, or air and oil vapour. The air in the mixture is sufficient to burn the gas or vapour completely.

The full flame of a miner's lamp should be well known to you; if it is not, then light a lamp and check off the following statements:—

Experiment.

The part of the flame next to the wick is a band of pale blue light; air and oil vapour are here well mixed.

The next part of the flame above the wick is less blue than the above, it consists chiefly of unburnt vapour. After the foregoing foundation of the flame there is the very visible luminous area, where the carbon of the oil is separated and becomes incandescent. Then surrounding the whole of the flame is the almost invisible mantle.

Having fully made out the foregoing parts it will be interesting to lower the wick and by so doing remove all the yellow from the flame.

Experiment.

Notice the difference between the position of the wick in the full luminous flame and its position when all the yellow is cut off. In the latter position there will be seen in the flame a dark band in contact with the metal tube of the wick and a blue band superposed on this dark band.

The dark band consists of unburnt vapour passing from the wick to the blue band where it undergoes combustion, and the blue band being well mixed with air shows no luminosity.

Experiment.

Take a candle flame, or a small gas flame, or a lamp flame, and using a mouth blowpipe blow air gently into the flame; the luminosity will disappear.

This method of mixing air and gas or vapour results in a loss of light but in an increase of heating power; it has practical applications for lighting as well as for heating purposes.

It is therefore very plain that if a sufficient quantity of air could be mixed with coal gas the yellow part of the flame would not be formed, and a vessel being heated would not be blackened by the soot or carbon.

The foregoing part of this book has in many ways brought us into contact with the necessity of air in combustion, and incidentally it has been seen that where the parts of a flame are colourless there is plenty of air present. If air is mixed with gas in certain quantities, on burning the mixture the flame is colourless.

Experience.

The incandescent gas burner, which is now known to every one, has four holes through which air passes and then mixes with gas which burns with a non-luminous flame, in this the mantle is supported. Gas stoves used for cooking purposes, or the heating of rooms, have air inlets, and after passing in the air mixes with the gas, a non-luminous flame being produced.

The burner called the Bunsen burner, used as a source of heat in science work, is historically and industrially of importance because it has given rise to all burners which mix air with gas. Prof. Bunsen of Heidelberg required a burner which would not blacken his vessels when being heated, and from this necessity and his scientific knowledge he devised the burner we use; it is shown in Fig. 74, p. 150.

Experiment.

Take a Bunsen burner and screw off the gas tube and then notice the gas nipple on the base of the burner; it is connected with the gas supply pipe. See that the ring or collar on the tube is capable of being turned so as to close or open the two air-holes.

The air flows in at the air-holes, or intake, as the coal gas rushes out of the fine gas jet; this uprush of gas is the cause of the flow at the air-holes; thus the outside air continues to pass into the tube through the "air intakes," one of which is shown in Fig. 74.

The air that is passed in mixes with the uprushing gas and all the carbon particles are burnt to carbon dioxide before they can appear as luminous particles which blacken a body when heated in a purely coal-gas flame.

The mixture of air and gas burns at the top of the tube; this is because the mixture flows out more quickly than the flame can travel down.

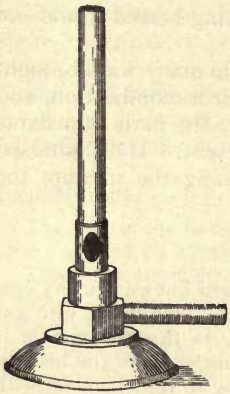

FIG. 74. — The Bunsen burner, showing an air-hole.

The size of the air inlet may be regulated by a sliding ring, which is usually when in use turned until the flame is entirely blue and burns quietly.

The Bunsen burner should not have its nipple burning when a flame is at the top of the tube, if this be the case there will be a disagreeable odour and soot will be deposited on any object being heated.

A practical application of the Bunsen burner, just as Bunsen constructed it for his laboratory except as regards size, is found in the heating of coke ovens. The following measurements and figures obtained from a Yorkshire colliery working coke ovens will be interesting :—

Length of burner . .	42 in.
Diameter	$1\frac{3}{8}$ in.
Air intake	$1\frac{3}{4}$ in. long, $\frac{3}{4}$ in. wide.
Collar for regulating intake	$2\frac{3}{4}$ in. depth, $1\frac{3}{4}$ in. diameter.
Diameter of gas nipple .	$\frac{1}{3}$ in.

Compare these figures with measurements of the Bunsen burner used in your scientific work.

There are fifteen burners to each coke oven, fixed directly to the main pipe, and each one consumes nearly 140 cubic feet of gas per hour. It is necessary to get the highest temperature, hence mixed with this 140 cubic feet are 700 cubic feet of air, so that gas is to air in the ratio of one to five. It is worth mentioning that the chambers under the coke ovens where these Bunsen burners are fixed have a temperature of 90° to 100° C., a temperature that bites your ears and nose as you pass through the chambers.

That the air is the active substance in rendering the coal gas non-luminous and therefore giving us the Bunsen flame may easily be shown.

Experiment.

Close the air intake of the Bunsen and a luminous flame is obtained, then gradually introduce air by opening the holes again and notice the whole flame becomes mantle-like. Test for any soot in the flame. Show the presence of an air current at the holes by holding a piece of smouldering paper; the smoke is drawn into the tube.

The air completely destroys the luminosity of the flame.

It will be interesting to know the amounts of air and coal gas which pass up the Bunsen tube; they are generally about 2 cubic feet of air to 1 cubic foot of gas, but vary slightly with different burners. The following figures show the variation:—

Air	63 per cent.	Air	71 per cent.
Gas	37 „	Gas	29 „
	100		100

Compare these figures with those for the industrial Bunsen burner.

Experiment.

Hold for a minute or two an inverted gas cylinder over a Bunsen burner when unlit gas is issuing; the air will be displaced. Apply a light to the mixture and note its burning with a non-luminous flame, also its sudden combustion throughout the cylinder.

It is worth noticing that although the time which elapses between the air finding its way in at the air intake holes and issuing at the top with the gas is very short, the two have nevertheless become uniformly mixed.

The Structure of a Bunsen Flame.

When the Bunsen flame is burning in a satisfactory manner it will be seen to have two very distinct parts: an inner part and an outer bluish part.

Experiment.

Light a Bunsen burner and then slowly bring down on to the flame a piece of wire gauze, as shown in Fig. 75. After holding it in this position for a few seconds a red-hot ring will be seen. What does this experiment prove?

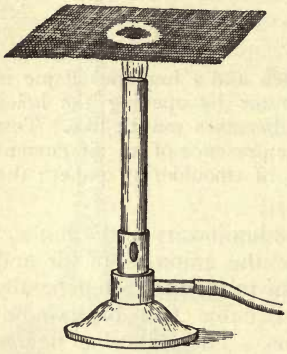

Fig. 75.—Showing the red-hot ring.

There cannot be flame in the middle, or the cold inner circle could not exist.

The gas which comes up the tube burns fiercely where it comes into contact with the air, but this fiercely burning outside protects the inside gas from the air and so its combustion is momentarily prevented.

We may therefore say that the gas at the top of the tube forms an inner cool part and an outer hot part, which is the real flame and mantle-like in appearance.

Depress, and remove quickly when charring commences, a piece of white paper on a Bunsen flame and notice the concentric

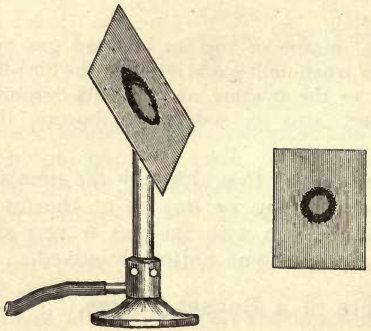

Fig. 76.—Showing the charred paper; a ring or ellipse is formed according to position.

circles formed. Get in the same manner, half-way up, a transverse section of the luminous flame.

The paper shows a charred ring with an inner circle of untouched paper. It is plain that we are dealing with an inside hollow cylinder of cool gas surrounded by a highly heated flame.

Further Experiments on the Bunsen Flame.

Introduce horizontally, and quickly, a match into the middle of the flame. Or fix a match in the tube by a pin penetrating the match at right angles and then light the Bunsen (see Fig. 77).

Lead out from the inner cone unburnt gas by a small tube held in this part and at an angle of 70° (see Fig. 78).

It is plain that the temperature of the mixed gas and air which feeds the Bunsen flame is lower than that required

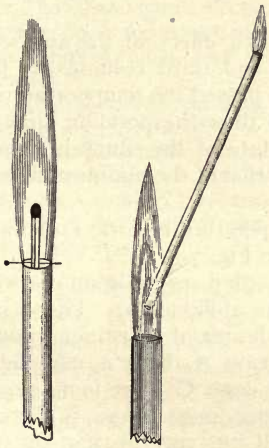

FIG. 77.

FIG. 78.

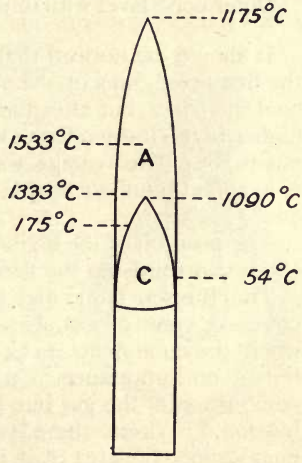

FIG. 79.—Diagram showing temperatures of different parts of the Bunsen flame.

to ignite the match; it even fails to get warmed enough for ignition to occur if left a long time in its position.

The Bunsen flame is therefore hollow, which means that it does not consist entirely of burning gas. If flame is de-

fined to be gas in a burning state then the word does not include the inner cone of unburnt gas; the word flame in ordinary life means the whole structure at the gas exit tube.

It will be instructive to point out that the temperature at different parts of a flame varies; the luminous and non-luminous flames of the Bunsen burner may be taken as examples.

Distance up flame.	Luminous flame.	Bunsen flame.
½ inch above burner . .	135° C.	54° C.
1½ „ „ . . .	421° C.	175° C.
Tip of inner cone, C. . .	913° C.	1090° C.
Centre of outer cone . .	1328° C.	1533° C.
Tip of outer cone . . .	728° C.	1175° C.
Outer cone level with inner tip	1236° C.	1333° C.

It should be noticed that the first effect of the air (see the first two figures in the second and third columns) is to cool the flame, but after these are passed the temperature is higher in the Bunsen flame than in the corresponding luminous parts. The average temperature of the Bunsen flame is in round numbers 894° C., and that of the luminous flame 760° C.

The position of the highest temperature is worth noticing, about two-thirds up the flame (see Fig. 79).

The Bunsen flame may be regarded as made up of two cones—a cone of gas, C; a cone of flame, A. There is, where the cone A fits on C, a small area of a distinct colour but of no importance. In the cone A there is complete combustion of the gas but in the cone C there is no combustion. Where these two cones meet there is fierce combustion, the area of it is small but very distinct by its greenish colour.

Flame—burning gas—has now been considered along with devices for increasing and decreasing its luminosity, depending on whether the flame is to be used for lighting or heating purposes.

The great change brought about in coal gas by its burning is made plain in the following table and statement.

Composition of unburnt coal gas:—

Hydrogen	51·4	per cent.
Marsh gas	34·3	,,
Carbon monoxide	7·4	,,
Nitrogen	2·2	,,
Ethylene	4·4	,,
Carbon dioxide	·3	,,
	100·0	

The components of burnt coal gas will be far simpler; there will only be three, viz. nitrogen, carbon dioxide, and water vapour. The water vapour condenses to water as soon as it cools.

Experience of Light without Flame.

The incandescent electric lamp, one variety of which is shown in Fig. 80, is to be seen in all tramcars, most public halls, and many private houses.

The lamp consists of a glass bulb, which is quite devoid of air, with a thin wire-like length of material of about 12 inches long and less than $\frac{1}{16}$ of an inch thick—called the filament; it is in loops, through which the current of electricity runs.

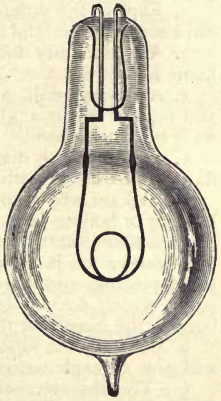

Fig. 80.—An electric lamp.

In public lighting a current of electricity passes along cables, made of copper, fixed below the surface of the street, but when the current comes to traverse the filament of the lamp it meets with great resistance, and having to force its way through, heat is produced; this heat makes the filament white-hot and so it gives off light.

No combustion can take place in the lamp because there is no air inside; the light is therefore derived from an incandescent metallic filament. In the older lamps a carbon filament was used.

Experience.

Most people are familiar with the pocket flash-lamp. The bulb part of the lamp contains a filament for the current to traverse; it may be seen by opening the upper cover. The dry battery, or dry cell, which fills the case has to be renewed in order to continue the lamp's light-giving power. These cells contain various chemicals, such as plaster of Paris, zinc chloride, and sal ammoniac, along with zinc or carbon rods.

The circuit or path for the current is completed by pressing a button; chemical action at once takes place in the cell, and this produces electricity, which, passing through the filament, is changed into heat and light. Compare the foregoing with the miner's electric lamps described on p. 102.

QUESTIONS.

1. Make a sketch of the flame of a miner's lamp showing the three parts. Which part of the flame would blacken a body if placed in it?
2. Explain the difference in the production of light between an incandescent burner and a bat's-wing one.
3. Are there any differences between a gas cap and the mantle of a flame?
4. A smoky, dull, and irregular flame becomes smokeless, bright and regular when a glass chimney is fixed around it, or when the wick is turned down. Explain these changes.
5. Describe with diagrams any methods of producing light without flame. Are these methods dependent on air for their light?
6. Explain why a coke fire will not blacken objects placed on it for heating or boiling purposes.
7. Carbon (soot) is often deposited in the fire-grate back or on its bars when a fire is burning. Observe all you can in connexion with the deposition and then give the reasons for it.
8. Which do you consider is the light-giver in an incandescent burner, the mantle or the burning gas? Give reasons.
9. Consider the following three pairs of facts of common experience, and give an explanation of each difference:—
   (*a*) The characteristic smell of coal gas.
   (*b*) The loss of smell on burning.
   (*c*) The deposition of soot on articles by a luminous flame.
   (*d*) The absence of deposit in a Bunsen flame.
   (*e*) The high temperature of the flame.
   (*f*) The heat of the match is all that is initially supplied.
10. Explain why a taper will not burn in coal gas. Name the gases into which a taper has turned when it has been completely burnt.
11. What is a flame? Methylated spirit burning gives a blue flame; do you think there is any incandescent carbon in it?

CHAPTER IX.

WAYS OF PRODUCING HEAT AND LIGHT.

In the production of light there is always heat preceding its appearance; only when the heat has become fierce does light begin to show itself.

In a pit there is a great deal of heat at a low temperature produced by the friction of one thing on another, e.g. coal tubs running on the rails, and there is always some coal being ground to a very fine and dry dust. The use of coal cutters in the pit must result in the making of the cutting part of the machine very hot, and fine coal dust is also produced. It is worth emphasizing that by both these processes fine coal dust is produced as well as heat. The inflammability of dry coal dust is one of the chief factors in pit explosions.

Experience.

That heat is produced by the rubbing of one substance upon another substance, or a piece of itself, is widely known. The joiner finds his saw gets hot as he cuts through a plank of timber, and even the sawdust is in a hot condition. Metal and wood when scraped or planed also show an increase of temperature, as do the scrapings and shavings.

If the material scraped, sawn, or planed off consisted of a *fine dry* dust then we feel certain that it might more easily catch fire by the heat produced, and so burst into flame, than if it were coarse and moist. The production of heat by rubbing, i.e. friction of surfaces on one another, is well known to all boys in the familiar prank of rubbing a button on a surface and then placing it on a friend's cheek. The heating of the hands on slipping down a long length

of rope is also well known. All movement of surfaces in contact produces big or little amounts of heat.

As far back as 1875 it was shown that a mixture of air and fire-damp, which could not be ignited by a naked light, showed a tendency to ignite when coal dust was added. The ignition of coal dust resulting in an explosion was shown in the experiments at Altofts in 1908 and 1909; gas was entirely absent in one experiment when the exploding mixture of coal dust and air blew one piece of a boiler shell, weighing 40 lb., a quarter of a mile.

In order to emphasize this point of the inflammability of dry dust, the following old methods of producing fire, before matches were invented, by primitive man are worth considering. One which was a world-wide process may be illustrated by the following experiment.

Experiment.

Take a round piece of wood, e.g. a ruler, and rotate it between the palms of the hand by sliding the latter backwards and forwards. Keep the lower end of the ruler on a piece of wood. Heat is produced where the ruler grinds on the wood. It might be detected by placing the bulb of a thermometer on the place rubbed. The hands and ruler also become warm.

In the primitive method dry, hard wood was used, and by the friction of the rotatory part hot wood dust was made.

Another process consisted of quickly drawing one piece of wood in the groove of another piece until heated wood dust was produced. In a similar process dry bamboo with a saw-like edge was used on another piece and the usual hot dust produced. In all cases this hot dust was arranged to fall upon very dry grass or dried hairy seeds of plants, similar to thistle or dandelion so as to ignite them. When fire had been obtained in this way a wood fire was usually kept continually going, often in a place of worship. The foregoing facts should bring home to us the inflammability of combustible substances when in a fine and dry condition; the finer and drier they are the easier it is to bring about their ignition. It is therefore plain that any source of high temperature in a pit, e.g. the bonnet of too hot a lamp, is

a source of danger if there be fine and dry coal dust present. Those who work in dry, hot, and dusty pits know that the inflammability of coal dust is counteracted by stone dusting the various parts of the pit; it is covering or mixing inflammable dust by a non-combustible dust.

The Development of the Match.

The way in which the human race progressed in the making of "fire" should be interesting to us; the foregoing paragraphs show the first steps to be the making of a hot dust, the next and the final stages in the production of a match has important lessons to the miner. As soon as mankind knew how to make steel they began to change the materials used in making "fire". Steel and flint came into action; flints are very similar to the hard pebbles found on the coast, sometimes they are used in paving streets. In the striking of flint and steel sparks were produced, and these red or white-hot sparks fell on dry tinder so arranged as to catch the sparks.

Experience.

The production of sparks by friction or grinding is a part of every one's experience. The brakes on the engine give a torrent of sparks when applied to moving wheels; the shoe placed on the wheel of a cart produces sparks as it is dragged over the stones of a street or road. The iron shoe of the horse and the iron nails of a man's boots are often producers of sparks when they come violently into contact with the paving-stones.

Fig. 81 shows a machine for making sparks; the cog wheels rotate a steel disc fixed on the same axis as the small cog wheel. A shower of sparks is obtained by pressing the piece of flint, shown in the figure on the supporting board, lightly against the edge of the revolving steel disc. On the right of the figure is a gas nozzle through which different gases may issue so as to experimentally find if the gas can be ignited by the sparks. By this particular machine hydrogen is instantly ignited, while the same temperature sparks fail to ignite marsh gas. Consider this in connexion with the employment in pits of coal-cutting machines which have increased very much during the last few years; the cutter

of the machine is a wheel or disc with chisels set in its rim. The rate at which the disc revolves, from sixty to eighty revolutions per minute, and the resistance it has to overcome in the cutting must produce much heat and often sparks, particularly where it cuts through "brassy" coal, and this no doubt makes the process not free from danger in a gassy pit. Coal-cutting machines electrically driven

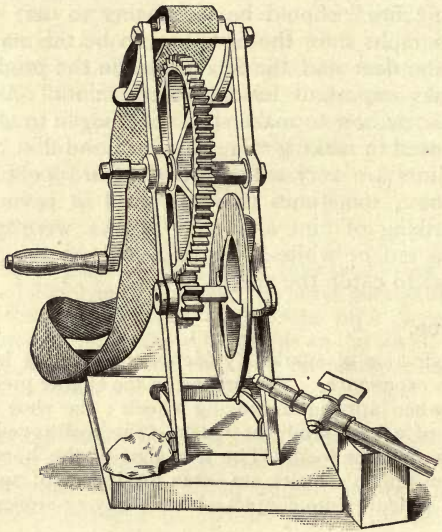

FIG. 81.—Machine for making sparks.

may give an electrical spark and so produce an explosion, as was alleged in the Wharncliffe Silkstone explosion of 1914.

The foregoing methods of producing a light would all be regarded as very slow if they had to be employed at the present day; it is important to notice that they all consist of making a substance hot by friction, and the substances used were not, except tinder, inflammable ones. The next step in the production of a light consisted of making a match, although different from the present-day one. The

match as we know it produces much heat and light for the small amount of friction given on the box surface: this is because the head consists of substances easily ignited, or in other words, of chemicals which are artificially made. The match flares up suddenly by chemical action; this flare is produced after the slight rubbing which starts the action.

Many chemical methods, i.e. methods involving the use of chemicals, were invented between the years 1780 and 1840 of producing fire, or a light as we should now say, but in the latter year friction matches came into existence.

One of the first kind of matches made consisted of a piece of wood with a brimstone head.

Experiment.

Take a small amount of sulphur, i.e. brimstone, and melt it over a flame turned down low; it may be melted on a tin lid or any bit of pot. When melted dip in bits of wood so as to put a cap of sulphur on them.

These matches might be used for carrying a light from one place to another, the presence of the sulphur on them helps to make certain of the wood-stick taking fire. They were at the beginning of the nineteenth century dipped into a mixture of phosphorus, oil, and wax, and then ignited by rubbing on a cork. The phosphorus ignited first, and then set the sulphur on fire, and this acted on the wood.

Johann Jrinyi, a Hungarian, improved on the sulphur-tipped match by adding phosphorus to the sulphur. *He learnt this from experiments made at lectures which he attended.* This produced the ordinary match which will ignite on any surface when it is rubbed sufficiently. R. Bell commenced the manufacture of this match, called a lucifer match, in London in 1832; it was ignited by drawing through sandpaper.

Experiment.

Strike a match and immediately try to blow out the flame. Can you do so before the head has completely burnt?

Notice the pitted nature of the head after combustion, and that the burning of the head is not as gentle as that of the stick.

Stopping the combustion of the head will not be easy to accomplish ; if it does occur it is because your blowing has cooled the head down below the temperature required for burning. Difficulty in stopping the combustion is due to the fact that its burning is independent of the air.

The pitted nature of the head and its vigorous combustion suggest we are dealing with a highly inflammable mixture ; in fact the burning of the head suggests a fiery mixture akin to an explosive.

Experiment.

Strike a match and immediately notice the colour of the flame of the burning head. Is there a change in the colour of the flame as it passes from match-head to stick ?

It will be noticed that the colour of the flame changes as the burning passes from the head to the stick. The stick burns with that type of flame common to oil, gas, wax, tallow, and coal gas ; it has a blue and a yellow part. The head is distinctly bluish-white as it flares, and it is uniformly of one colour ; a reference to the Table of Colours on p. 8 will tell us it has a very high temperature.

Experience.

Recall the experience you have had in connection with fireworks ; in burning they give various displays of colour, and burn with great energy. The colour of the flame of the match-head may be recalled as having been seen during a firework display.

In match-heads and fireworks the vigour of the burning is due to their containing chemicals rich in oxygen ; the chemicals which burn do not have to get their oxygen from the air, it is part and parcel of the substances mixed in the head. The colour of the flame shows the head contains nitrate of potash, or chlorate of potash ; it is the potash which gives the bluish-white or lilac-coloured flame of the burning head.

Why should any consideration be given to the making and burning of a match ? Well, it brings us into contact with two sources from which a burning substance may get its oxygen ; one source is from the air and the other from

the burning substance itself. The latter is always the case with fiercely and rapidly burning substances such as explosives and fireworks. A match and its changes on combustion afford an excellent lesson in chemistry, and so merit our consideration on account of their familiarity.

Experiment.

Try if a match-head will burn in carbon dioxide. This may be done by putting an unstruck match in a jar of the gas and touching the head with a hot rod. Or strike the match in the jar and see if the match will burn beyond the head part.

The apparatus shown in Fig. 82 may be used for the purpose, the unstruck match being fastened on a piece of wire and then touched by a hot rod of any kind of material.

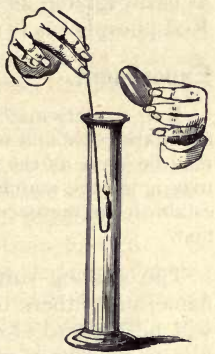

FIG. 82.—Burning a match-head fixed on to wire, in a cylinder containing carbon dioxide.

The condition of a match in the burnt and unburnt states brings us face to face with a great change, such a change that it might be regarded as a great transformation if it were less familiar to us. By fire the clean, smart-looking match is transformed into a useless substance which soils the fingers. The change is called a chemical change, because there are great differences between the substances forming the match before and after igniting it. The change of colour, the production of a smell, the outburst of flame, the permanent alteration in appearance all indicate a chemical change.

The ease with which a match will ignite tells us that some solid substances are easily inflammable; the rubbing, or friction, of the match on the box surface cannot produce much heat, but there is sufficient to set the head ablaze.

The Chemical Teaching of a Match.

In the experiment on removing oxygen from air by using phosphorus a hot rod was used to bring about its

ignition. Phosphorus, which goes by the name of yellow, or white, phosphorus, has to be used with care, otherwise it quietly bursts into flame. It was used in match-making up to the end of the year 1909, but then forbidden by law because it is poisonous. If yellow phosphorus is heated in carbon dioxide gas it changes to a red colour and becomes far less active and vigorous. It is a curious result, for this red phosphorus remains unaltered in the air, is not as easily ignited as yellow phosphorus, and is not poisonous. Red phosphorus is now used in match-making.

Experiment.

Rub a safety match gently on the striking surface of the box in a dark place and see if any light is produced. A bright line may be seen as the match passes along the surface, the heat may ignite the match-head. Set fire to the striking surface and establish the presence of phosphorus in it by smell and combustion.

The striking surface should be set on fire by a Bunsen flame, and if there be phosphorus in it a wave of combustion will be seen to slowly travel over the surface, and white fumes, which possess an unpleasant garlic-like smell, will be perceived.

The bright line seen in the experiment is due to the heat, produced by the friction, turning the red phosphorus in the striking surface back again to yellow which immediately inflames.

If the foregoing experiment is done in the dark it will then be seen in the case of safety matches that the phosphorus on the box is first ignited and after this the head.

Experiment.

By burning matches prove the production of the following substances during combustion: Carbon, ash, carbon dioxide.

Some carbon has burnt away as carbon dioxide; this is easily proved by burning the match in a bottle or gas jar (see Fig. 82, p. 163). The vessel may be held over the burning match; in any case the carbon dioxide is detected in the vessel by shaking with lime water.

A match after burning usually shows three parts: an unburnt part; the part held in the fingers, nearer the head a black part; and at the head end a frail fluffy part of a grey or white colour.

This latter part is the ash, and is incombustible material. In the ash part of the burnt match the carbon, liberated from the wood of the stale as the match burnt, has burnt completely away. The black part left is carbon; this would undergo further combustion if put in a gas flame and leave behind a further small amount of ash. The two substances then remaining behind in the burnt part of the stale are carbon and ash; one black and combustible, the other white, or grey, and incombustible.

Water may be seen on both head and stale during the combustion of a match. Its source may be from the dampness of the head, or of the stale, but there is a small quantity *made* from the match constituents by the burning.

These changes should be thoroughly thought out. The match consists of a piece of wood and a dry paste forming the head. The blackness of head and stale after burning shows that carbon is in the original paste of the head, and in the wood of the stale. Wood contains carbon, despite the difference in the colour of the two things; it is present in the colourless wood and heat liberates it.

If carbon is present in a substance heat will generally liberate it, and then if heating is still continued the carbon burns to the invisible gas carbon dioxide.

QUESTIONS.

1. State several ways by which heat, without light, may be produced in the pit by rubbing and grinding.
2. State all the ways by which light, accompanied by heat, is produced in the pit.
3. Are there any processes going on in the pit which produce heat alone and yet cannot be placed in question 1?
4. Is it dangerous to rub a substance which is an inflammable one? Give an example.
5. Which do you think is more likely to ignite by friction: sawdust or wood, damp or dry paper? Give reasons.
6. How may it be proved that a match contains carbon? Describe an experiment to show that carbon often exists in the state of vapour.

7. Will heat be produced in grinding rock to form stone dust for pits? If so, how do you explain its not igniting? Is there any difference in the inflammability of the rock and its dust?

8. Give a list of solid and liquid substances which are inflammable. What objections are there to storing them in a pit?

CHAPTER X.

THE INFLAMMABILITY OF SUBSTANCES.

THE previous chapter has brought us into contact with substances which when made hot do not ignite, yet falling on other substances finely divided these are ignited. It is plain then that substances vary in their ease of ignition.

Experience.

The heated iron used in laundry work must when not actually in use be resting on a special support ; if it were left on the article being laundered, e.g. cotton material, ignition might occur. The ignition-point of cotton is therefore lower than that of iron or steel. A hard coal is more difficult to ignite than a soft coal ; hence the latter is often preferred for grate-fires which are made daily.

Iron has a very high ignition-point, the fire in the grate does not ignite it, but most of us have seen the bright sparks flying from the iron as it runs molten from the furnace or as it flies away from the blacksmith's anvil as he hammers it ; in either case the particles are burning.

The ordinary match consists of substances which are easily ignited, but yellow phosphorus is even more easily ignited than a match.

There are substances known which as soon as they come in contact with the air burst into flame ; their ignition temperature is therefore very low. There are some substances in the gob of the pit which easily produce heat ; and hence they are very dangerous owing to their ease of breaking into fire and flame.

Experiment.

Throw a small piece of calcium phosphide in water to which a *small* quantity of hydrochloric acid has been added; a spontaneously inflammable gas is liberated. A porcelain dish is a convenient vessel to use.

Calcium phosphide receives its name from its two constituents: calcium and phosphorus. Compare the name calcium carbide with that of the substance from which acetylene gas is obtained. Calcium is a metal which can be got out of lime or limestone; it is a very abundant metal in this locked-up state; by itself it is not very useful and therefore is not very common. The joint action of water and the phosphide ends in the making of an invisible gas—composed of hydrogen and phosphorus—which as soon as it rises through the water surface, and therefore comes into contact with the air, ignites, producing white fumes. The white fumes are not the gas but the gas burnt, they are oxide of phosphorus formed by the oxygen of the air and the phosphorus of the gas uniting together.

The foregoing action finds a practical application in the apparatus known as Holmes' Signal Lights for marine purposes. This consists of a tin vessel containing calcium phosphide; it has a tube passing through the bottom of the can and a small hole in the top for the gas to find its way into the air. The board in which the can is fitted forms the two wooden wings for floating the can. When the appliance is thrown into the sea water finds its way to the calcium phosphide, and the gas liberated issues out of the jet; it ignites itself as it comes in contact with the air.

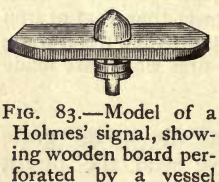

FIG. 83.—Model of a Holmes' signal, showing wooden board perforated by a vessel containing the phosphide.

Experiment.

Dissolve a bit of phosphorus in a small quantity of carbon disulphide. Pour some of the liquid on a filter paper and hang up to dry. The phosphorus will ignite.

Rub quickly a few times on the edge of the bench a knife, or warm a glass rod on the arm of your coat by friction, and immedi-

ately touch it with a *bit* of dry phosphorus. Note what happens. Carry out both these experiments far from any flame.

Carbon disulphide dissolves phosphorus, and the latter, like all other substances when dissolved, exists in a very finely divided state ; finer than any form of grinding can produce. Only particles of gases are finer than the particles of a liquid. As soon as the liquid disulphide has evaporated the phosphorus alone is left on the surface of the filter paper ; owing to its fineness it is vigorously attacked by the oxygen of the air. This attack results in the production of heat and the phosphorus fires. In the second experiment the heat necessary to start the combustion is derived from the knife ; compare this with the first experiment. The comparison will teach us that when a body does burst into flame spontaneously, it has before doing so been accumulating heat unnoticed by us. This is the case previous to the sudden outburst of fires in the gob.

The same fumes are produced here as in all cases when a substance containing phosphorus burns, they are always oxide of phosphorus.

If the atmosphere contained sufficient heat at a high enough temperature it would at once ignite the phosphorus, as the warmed knife does, and phosphorus would be spontaneously inflammable. When phosphorus does ignite in the air without our heating, it has been previously accumulating heat, and in time it gains enough to bring it to its ignition-point. The ignition-point of phosphorus is 34° C.

Most things require Warming to start Burning.

This paper is combustible and the air around it is a supporter of combustion. Why does not the paper burn? It needs warming or heating to a certain temperature before the action between the air and paper, called burning, begins. The temperature required to begin the action is called the ignition or kindling-point of the paper. Compare the expression with the similar one "boiling-point"—the ideas are much the same. The boiling-point of a liquid is that temperature at which bubbles of its vapour leaves its surface, e.g. water boils at 212° F. or 100° C. The idea in the expression is therefore the *temperature* of the water when it changes from liquid to steam. The idea in the expression

"ignition-point" is the *temperature* at which the substance begins to burn. Carbon disulphide has for its ignition-point 120° C., its boiling-point is 46° C.

If the temperature at which a body ignites is near to the ordinary temperature of the air, it is said to be easily inflammable and its ignition-point is represented by a small number of degrees, e.g. phosphorus, as just pointed out, 34° C.

A substance whose ignition-point is far above the temperature of the air will have a big number to represent it, e.g. marsh gas ignites at 750° C., i.e. a temperature 7½ times that of boiling water is necessary to start its combustion. Now as marsh gas, or fire-damp, may be ignited by a spark, it follows that the temperature of the spark must at least be 750° C.

The ease of "catching fire" varies with different substances ; it only requires a low temperature to start a match burning. This low temperature is higher than the air's temperature, otherwise a match would be spontaneously inflammable, and it would have to be made of different materials from those at present used.

Experience.

Consider the stages in the burning of a match. The head conslsts of easy inflammable material which is ignited by the small amount of heat produced by friction. The stick of the match is thin and dry so that it may easily catch fire from the quickly burning head. In order to make certain of the stick catching fire several makes of matches have their sticks dipped into a combustible material such as molten paraffin wax.

Substances are used in the match-head which have a low ignition-point, and on striking its flame hands on the combustion to the wood which has a high ignition-point.

The match illustrates the grading of things according to their ease of inflammability and combustibility, in order to give ease at the starting of the burning and then a flame lasting for a few seconds. This few seconds is quite sufficient to reach the ignition-point of other things, e.g. gas, fires, cigars, etc.

Experiment.

Place a *small* amount of carbon disulphide in a porcelain dish. Light a Bunsen burner; keep it far away from the carbon disulphide. Heat slightly a glass rod in the burner and then hold it over the disulphide; if the vapour does not ignite increase the temperature of the rod until the vapour does ignite. Turn on the tap of another Bunsen and try to light the gas by a hot rod. A temperature of about 700° C.—bright red heat—will ignite the gas.

A variation of this experiment is to try to ignite both disulphide and gas with a glowing piece of wood; it will fail in the case of the gas.

Or two gas cylinders may be filled one with coal gas and one with carbon disulphide vapour—a drop or two of the liquid will soon fill the cylinder—and the heated rod introduced into each.

Carbon disulphide boils at 46° C., a low temperature for a liquid to boil, and the result is that it is very quickly converted into a vapour. The vapour is a heavy one, and therefore does not quickly get away. As the liquid turns into vapour it becomes mixed with the surrounding air and it may then be ignited by a hot rod, at a temperature of about 120° C.; this temperature is therefore its ignition-point. If a liquid is easily converted into vapour which is combustible, then the liquid is a dangerously inflammable one.

The following experiment may be performed with the ordinary incandescent mantle burner.

Experiment.

Turn on and light the gas, and allow the mantle to get thoroughly hot. Now quickly turn out the gas and whilst the mantle is *bright* red hot, turn on the gas: it will ignite. If the mantle is allowed to go to a *dark* red heat, the gas will not re-ignite.

The ignition-point of coal gas is very much higher than that of carbon disulphide, it is said to be from 650° C. to 700° C.

Experiment.

Place a small quantity of paraffin oil in a porcelain dish and try to ignite the oil with a lighted match. It will not ignite. Place the dish on a tripod as shown in Fig. 84 and warm gently,

applying a light to see if the vapour ignites. If the temperature of the oil were taken when the vapour just ignites the point of ignition is obtained.

The fact that oil cannot be ignited on the surface previously to warming is due to two things, an insufficient amount of vapour is coming off and it is at too low a temperature.

As the oil is warmed the vapour particles over the surface get more and more numerous and their temperature higher, and also the air particles; in this way an explosive mixture is formed and there is a flash when the light is applied.

Imagine that the mixture of air and vapour particles is formed in the reservoir of an oil lamp, then if the mixture becomes hot enough it ignites and the vessel is shattered: the explosion is a dangerous one. When the mixture is fired in an open space, as in the experiment, there is no danger, and no damage will result if caution is observed. The comparison brings out the difference between firing a mixture of air and inflammable gas in closed and open spaces. In the open air the heat of the firing drives apart the air, as a flash of lightning does in cutting its way through, but it joins again and is unbroken. In the closed space the heat of the firing drives the air against a wall of some type, and unless it is extremely strong the wall is shattered.

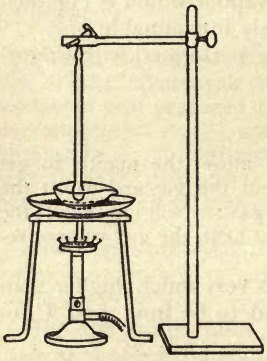

FIG. 84.—Apparatus for finding the flash-point of a liquid.

Flash-point of Kerosene.

C Imbed a porcelain dish in sand on a tin lid or a sandbath and place on a tripod (see Fig. 84). Fill, almost, the dish with kerosene and hang a thermometer into the oil, suspending it from the ring of a retort stand.

Raise the temperature of the oil slowly, about 6° per minute, with a small flame. Occasionally pass a flame over, and ½ in. above, the surface of the oil. Read the thermometer when there is a flash; the number of degrees registered is the flash or ignition-point.

Allow the liquid to cool slightly and repeat the experiment for a corroboration of the flash-point obtained.

Heat is produced each time the vapour is flashed and this affects the thermometer, so care should be taken not to read the temperature when the thermometer is affected by the heat of the flash. It is therefore advisable to notice the temperature just before an attempt to flash the vapour is made.

The temperature of the vapour just before it ignites will be the same as the liquid in the dish, this temperature is the flash-point.

The flash-point is an index of the dangerous nature of the oil; if the flash-point is low it is a dangerous oil, if high it is not so dangerous. The danger comes from the ease of the vapour flashing and producing an explosion if in a confined place, e.g. a lamp.

If the ignition-points of coal gas or fire-damp were higher than they are—650° C. and 750° C. respectively—it would be more difficult to produce an explosion either in a house or in a mine. Paraffin oil is required to have a flash-point of not less than 73° F. (22·7° C.); the requirement should be as high as 100° F. A low-flash point is a great danger; it was a greater danger several years ago when petrol was not separated from petroleum, as it is now, and many disastrous lamp explosions occurred in houses. The demand for petrol has resulted in the separation of it from petroleum, and so the constituent of petroleum which has a low flash-point has been removed. In this way the coming of the petrol engine has reduced the risk of a lamp explosion.

Experience.

Search out the instructions given on labels to avoid the difficulties and dangers in connection with the storage of small quantities of inflammable liquids, e.g. a bottleful of methylated spirit, benzoline, naphtha, etc.

Their catching fire is connected with the ease that they give off a vapour, and the danger of bringing a vessel full near the fire is owing to the likelihood of air mixing with their vapour in the storage vessel, be it bottle or tank, and

then exploding. It would be an explosion in a confined space and so likely to be disastrous.

Vapours and gases consist of very small particles, of such a degree of fineness that we cannot form an adequate idea of it; hence they are in the right condition for quick combustion, i.e. for exploding.

That fineness or thinness makes the beginning of combustion easy is again illustrated by the ease with which shavings burn compared with that of wood. All the foregoing facts help to show that the fineness of division of coal dust in the mine is no doubt the chief factor in starting a coal-dust explosion, and it may not always require the same temperature to do it.

Experiment.

Take a tin lid and place in it some finely divided iron, known as "reduced iron," then hold it over the Bunsen burner. Notice that the iron burns very easily. Drop a bit of the iron in the Bunsen flame; it will burn.

Iron in the solid state, e.g. girders or other iron structures, is used because it does not burn, a temperature 16 to 18 times that of boiling water is even required to melt it. Fineness of division therefore helps the ease of combustion of iron; it is also shown by the brilliancy of the hot sparks that fly from the smith's anvil.

There is plenty of evidence in the pages of this book to show that fineness of division is conducive to inflammability.

The influence of fineness of division on the combustibility of coal is well shown by experiments which gave these results:—

In bits of coal not less than half an inch in size they did not take fire below 850° F. Dust composed of bits about $\frac{1}{32}$ of an inch in size took fire at 425° F., but coal in a very fine powder took fire at 212° F., i.e. the temperature of boiling water, the coal being exposed to air heated to the temperature stated.

Practical Application to Mining.

Most miners have noticed that a safety lamp is more easily lighted when the wick is warm than when it is cold;

this is particularly noticeable when the lamp is lit electrically.

Those who have used safety lamps burning naphtha or benzine will probably have noticed that they light much more easily than lamps burning colza or paraffin. Owing to their low ignition-point naphtha and benzine must be stored in the lamp-room in a special manner in order to prevent them taking fire. A method of doing this is to connect up the storage tank to a cylinder of carbon-dioxide instead of allowing it to be open to the atmosphere. When spirit is drawn out of the tank carbon dioxide instead of air takes its place, and thus prevents the possibility of an explosive or combustible mixture being formed.

Oil is used in the pit for various purposes, and accidents have been caused by it becoming ignited.

In South Wales a fatal accident was caused by the apron of a lamp cleaner catching fire from an open grate in the lamp-room.

In the North of England a serious underground fire was caused by a paraffin lamp used for heating the carburetter of an oil engine catching fire. The oil for the engine was supplied from a tank at the surface, having a capacity of 320 gallons, through a $\frac{3}{4}$ inch pipe, and the whole contents ran to the engine and increased the fire.

In Scotland a serious and fatal underground fire was caused by oil in the box of the controller of an electric motor becoming ignited. There were only two men in the pit and the smoke did not reach their working place, but at the end of the shift as they were coming outbye towards the shaft they met the smoke coming in towards them. They stopped and consulted as to what they should do, and finally decided to try and get through the smoke by the intake, and the younger man did so safely, but the other, who was 57 years of age, was overcome, and when found was dead. The management thought that the fumes from the oil passing over the top of the fuses were ignited by a fuse blowing. Another theory was that a short-circuit occurred between the terminals inside the box just above the oil and this set fire to the oil.

Reference has been made earlier in this chapter to

"spontaneous ignition". A very important class of mine fires—gob fires—are due to this cause.

Cause of Gob Fires.

Probably the principal cause is the heating set up by the coal, left in the gob or goaf, absorbing oxygen from the air. Once this action is started under favourable conditions, the temperature gradually increases until the point of ignition of the coal is reached. One of the first signs of a gob fire is the appearance of moisture on props and packs. This is called "sweating". The next sign is a smell resembling that of paraffin or petrol, which is followed by the true "gob stink," a characteristic smell which it is not easy to describe.

Fires due to spontaneous ignition may occur in pillars of coal, near faults, or in the waste or gob from which the coal has been worked.

How to Deal with a Gob Fire.

A gob fire may be dealt with by building stoppings round it and so excluding the air; by the use of inert gas such as nitrogen or carbon dioxide, or by driving roads to the fire, filling it into tubs and sending it out of the pit. The method of filling out the fire is probably the best one, particularly in a mine worked on the Longwall System. The source of danger is entirely removed, and if the fire is tackled in its early stages the difficulties to be overcome are not too great.

Fig. 85 shows the method of driving roads or "scourings" to a fire in the goaf of a Longwall working. When the fire is reached sand is thrown on to it and it is filled into tubs of iron or steel. Sometimes a single scouring is driven which is ventilated by means of metal air pipes which are not liable to take fire.

When a pair of scourings are driven they are ventilated by means of air pipes until a connexion can be made between them when the ventilation takes the path shown in figure.

The roof of the scouring may be supported by steel girders, the spaces between them—if the roof requires it

—being filled in with metal plates resting on the girders. It is advisable to spread stone dust freely in the neighbour-

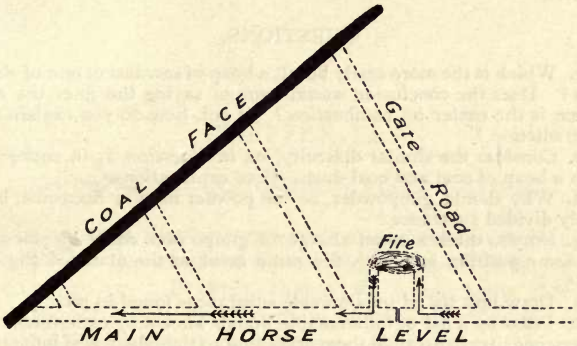

FIG. 85.—Showing a pair of scourings driven to a gob fire.

hood of the fire with the object of preventing an explosion of fire-damp—if one should occur—from spreading to other parts of the mine.

Prevention of Gob Fires.

To prevent gob fires air must not be allowed to enter the gob. Airways, both intake and return, should be large so as to make the difference in pressure between the intake and return as small as possible, and in this way prevent the air short-circuiting through the gob. In gate roads roof may be taken down and the packs buried, and old gate roads which are out of use may be packed off with sand and stone.

Hydraulic storage is highly recommended in some quarters as a means of preventing gob fires. The coal taken out of the mine is replaced by material from the surface, such as sand, gravel, stone or any cheap non-combustible material. This material is ground up and washed down pipes which lead to the part of the gob requiring filling. The solid matter remains in the gob and the water is pumped back to the surface and used over again.

Many advantages are claimed for this system, but it has not yet been adopted in this country to any great extent.

QUESTIONS.

1. Which is the more easily burnt, a heap of sawdust or one of shavings? Does the conclusion warrant you in saying the finer the substance is the easier its combustion? If not, how do you explain any contradiction?

2. Consider the similar difficulty, as in Question 1, in connexion with a heap of coal and coal dust. Give explanations.

3. Why should gunpowder, or the powder used in fireworks, be a finely divided substance?

4. Do you think a small charge of gunpowder could be placed in the same position and with the same result as the match in Fig. 77, p. 153?

5. Draw up a list of inflammable substances found in pits.

6. Draw up a list of inflammable liquids known by experiment and experience; try to arrange them according to their degree of inflammability and give reasons for your so doing.

7. Find out and describe the manner in which inflammable liquids are stored in the lamp-room of your pit. Give reasons for the method adopted.

CHAPTER XI.

SUBSTANCES CONTAINING FIXED OXYGEN.

We have learnt that nitrogen and oxygen exist in the air and almost form the whole of it: see the Table of Composition given on p. 37. Between these two constituents there is no bond of union, each particle of oxygen exists independently of each particle of nitrogen. Now although nitrogen is the largest in amount it is not of so much importance as oxygen on account of the activity of the latter. The activity of oxygen and the inactivity of nitrogen is well illustrated by the experiment, given on p. 22, for the separation of nitrogen from the air. Phosphorus is used because it and oxygen actively attack each other; it is a substance which put in the air draws the oxygen particles to it and then holds them firmly and securely. Now although this is the case with phosphorus and oxygen, nitrogen and oxygen even at the high temperature of burning phosphorus do not attack each other together.

In the presence of an electric flame of about 3500° C. temperature, nitrogen and oxygen particles of the air attack each other, enter into union, and this united product of oxygen and nitrogen, called oxide of nitrogen, attacks the water present in the air and forms an acid. On account of its containing nitrogen this acid is called *nitric acid*, but its most important constituent is oxygen.

Nitric acid is a very active acid, most substances being attacked by it; in such actions new substances are produced.

Experiment.

Dry over the Bunsen burner (preferably in a draught cupboard) a small quantity of sawdust in a sand tray. When the C

dust begins to char and shows patches of bright red take away the burner and drop on it, drop by drop, strong nitric acid ; notice the incandescence, possibly flame is produced.

An old tin lid will do for the carrying out of the experiment.

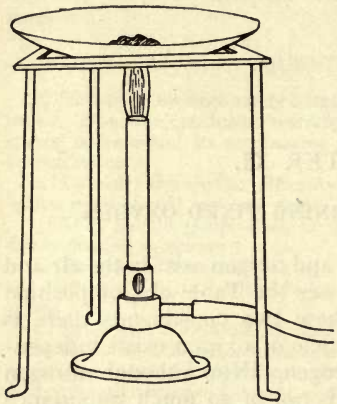

FIG. 86 —Apparatus for heating sawdust on an iron tray.

This vigorous combustion shows that heat is produced, but the production of carbonic acid gas is lost sight of owing to its being colourless. Red fumes which tell us we are dealing with nitric acid will be seen. This experiment is very important because it shows the burning power of bound oxygen. It is necessary that we should learn some further properties of nitric acid, therefore perform the following experiment.

Experiment.

Place a bit of copper, a shaving or a turning, in a test tube, and then add a few drops of strong nitric acid. Changes are at once seen ; red fumes are given off, a green solution is formed, and the liquid becomes hot.

It should be carefully noticed that the action starts without any heat.

All that goes on is not seen, but the red gas spoken of above is the oxide of nitrogen ; it is driven off from some of the nitric acid. The green solution contains the copper which has been dissolved by some of the nitric acid. This green substance is called nitrate of copper ; its name emphasizes its formation from nitric acid and copper, and also tells its composition. The aim of scientific names is to tell something of the components of a substance.

Experiment.

A few drops of nitric acid evaporated in a porcelain dish gives off red fumes and leaves no residue ; it is entirely a liquid.

If, on the other hand, the green solution called nitrate of copper is placed in the dish and the liquid slowly evaporated a green solid would remain ; this is solid nitrate of copper, the copper having fixed some nitric acid.

Substances made from Nitric Acid.

Experiment.

How to make a solid substance called nitrate of potash.

Place in a porcelain dish a small piece of caustic potash, about the size of a pea, and add, drop by drop, dilute nitric acid,

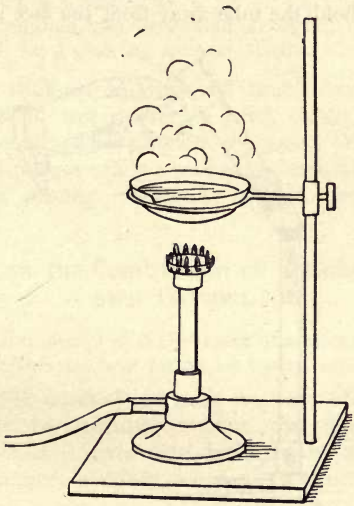

FIG. 87.—Apparatus for evaporating away water from a dissolved substance.

until the potash has dissolved and the solution after well stirring turns blue litmus paper red. Now evaporate off all the liquid over the Bunsen flame, moving the flame about as the liquid gets pasty. Finally it becomes dry and a white solid is obtained.

If the new substance is to have a scientific name, one denoting its constituents, it should be called nitrate of potash, the word nitrate denoting its nitric acid part.

Nitrate of potash is very different from its two constituents, it is a neutral substance. The caustic, i.e. the corrosive property of the potash as well as the acidity of the acid are lost. Nitrate of potash is used for preserving food from decay, and in making gunpowder and other explosives. The new substance is that popular and familiar substance saltpetre; "villainous saltpetre" as it is often called; get a specimen and taste it.

Experiment.

Take some nitrate of potash and powder it, then mix with some powdered charcoal. Place a small quantity of the mixture in a dry test tube, hold the tube away from the face and heat care-

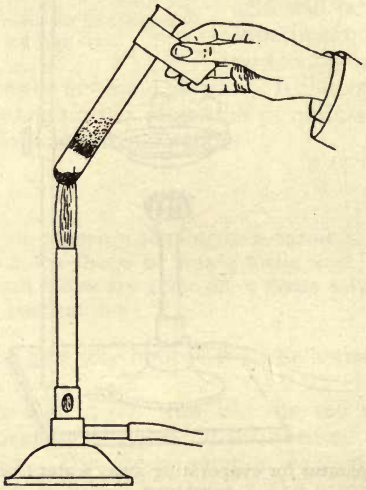

FIG. 88.—Method of heating a small quantity of a substance in a test tube.

fully. A fierce action goes on and sparks of red-hot charcoal are formed.

The burning of the charcoal is due to its being attacked by oxygen of the nitrate, forming carbonic acid gas. Nitrates are ready to attack most things when they are warmed in their presence. The mixture is only one constituent short of being gunpowder.

Experiments on Nitrates, etc.

In all the following experiments use a small quantity of the substance, hold the tube with the glowing splinter just in the mouth of the tube and away from the face.

Heat strongly over the Bunsen flame in a dry test tube any one of the following nitrates: nitrate of potash, nitrate of lead. Detect the oxygen as it is liberated by a glowing splint of wood which will burst into flame.

Repeat the foregoing with chlorate of potash and oxide of lead separately heated in a test tube.

Nitrate of ammonia may be heated strongly; it is slightly explosive and will set a glowing splinter aflame.

It may be difficult to drive off much oxygen from the nitrate of potash, but nitrate of lead, oxide of lead, and chlorate of potash easily give off the gas. We have learnt that nitrate of potash easily attacks charcoal, and this it does by its oxygen coming off easily in the presence of the charcoal.

Experiment on the Combustion of a Substance by its own Oxygen.

Heat a small quantity of dichromate of ammonia in a dry test tube and notice the red heat produced by its combustion.

Very vigorous combustion goes on, and after its starting the tube may be withdrawn from the flame but combustion continues. If air were excluded by a layer of sand over the substance, combustion would still proceed easily.

Oxygen containing Substances.

An explanatory note on some of the substances just used will help to form exact ideas of them.

Nitrates are substances made from nitric acid and a metal or other substance; they are very rich in oxygen.

The word oxide denotes a substance which contains oxygen and another substance, e.g. oxide of lead. An oxide of lead is used by plumbers under the name of "red lead"; it contains 90·6 per cent of lead and 9·4 per cent of oxygen. On heating it gives off some of its oxygen and changes to a yellowish oxide containing 92·8 per cent of lead and 7·2 per cent of oxygen. A brown lead oxide contains 13·4 per cent of oxygen and the remainder is lead.

Chlorate of potash and dichromate of ammonia are very rich in oxygen; it may be said that their names do not declare this fact to you. To a chemist the names do, because words denoting chemicals ending in -ate, or plural -ates, signify there is oxygen in them. The parts chlor and chrom of the words mean there are substances in them known as chlorine and chromium, the former a gas, the latter a metal. It is plain therefore that the mentioned substances chlorate and chromate contain three things each.

Glycerine Nitrate.

The last nitrate we shall study is often called "nitro-glycerine"; it is one of the best-known constituents of explosives. Dynamite contains 75 per cent of it.

Experiment.

Make a mixture, in a test tube, of one drop of strong nitric and four drops of strong sulphuric acid. Cool it well under the tap by allowing water to run on the outside of the tube. Add one drop of glycerine to the acid mixture. Pour the solution obtained into another test tube half full of water. Nitro-glycerine separates out as fine globules of a heavy whitish oil.

When the oil has been seen and identified pour all the mixture down a drain and then allow the tap to run for a few seconds.

The sulphuric acid simply helps the nitric acid to attack the glycerine; the changes in the properties of glycerine after it has become altered into glycerine nitrate are worth noticing. Glycerine, which is so well known, is a thick liquid heavier than, and soluble in, water. It is sweet and not explosive. Glycerine nitrate is insoluble in water and explosive. These changes are a further lesson in chemistry; the science that shows that when a body changes or adds to its original constituents it changes its qualities or pro-

perties. In order to show how largely and widely nitrates are used in the making of explosives, the following examples may be considered. They are taken from the explosives in the Coal Mines Order of 7 April, 1914:—

Commercial Name of Explosive.	Percentage by Weight Present.
Abelite, No. 1	Nitrate of Ammonia, 70 per cent.
Arkite . .	Nitrate of Glycerine, 33 per cent.
	Nitrate of Potash, 28 per cent.
Duxite . .	Nitrate of Glycerine, 33 per cent.
	Nitrate of Soda, 29 per cent.
Excellite .	Nitrate of Glycerine, 6 per cent.
	Nitrate of Ammonia, 50 per cent.
	Nitrate of Potash, 21 per cent.

Speed of Travelling of an Explosion.

Make a narrow train of gunpowder on a long board. Ignite at one end and take the time for the ignition to travel to the other end. Calculate the speed in feet per minute. Notice the difference between the unburnt and burnt states of the powder.

In a particular experiment the train was 5 feet long, the time of travelling from end to end 4 seconds. Hence the speed is 75 feet per minute.

The smoke which is produced by the combustion should be noticed inasmuch as it quickly rises to the ceiling of the room and then slowly falls again. Why does it do so?

Checking the Speed of the Explosion.

Make a similar train to the first one and then sprinkle stone dust, or fine sand, on its surface. Ignite the train and take the time of passing of the ignition wave from one end to the other.

In the particular case above mentioned it was found that the time was increased by sand to 8 seconds, hence the velocity had been reduced to $37\frac{1}{2}$ feet per minute.

Compare this action with the addition of incombustible material to flannelette in order to render the latter less inflammable.

In some further experiments to find the influence of leaving gaps in the train of powder and of mixing it with stone

dust obtained from collieries, the following facts were obtained :—

With gaps at least a half inch in length the speed of ignition along the train was increased; it is plain therefore that the ignition jumps across a gap quicker than it travels through the train, the time was only 3 seconds. It was found that a mixture of stone dust and gunpowder in the proportion of 3 cubic inches of the former and one of the latter, laid as a train would not ignite.

A mixture of one part of each constituent ignited.

The Explosive Force of Gunpowder.

Gunpowder, which consists of sulphur, nitrate of potash, and charcoal, must be a very uniform mixture, or it would not burn instantaneously, i.e. explode. The substances must also be finely divided, then it will quickly fire when once ignited.

Gunpowder burnt in the open air has no explosive force, but shows interesting effects. Much white smoke, i.e. well-burnt smoke, and invisible gases are produced: carbon dioxide, carbon monoxide, nitrogen, and a small amount of marsh gas. Despite the fact that the smoke contains gases heavier than air a great cloud rises up at a good speed owing to the heat produced expanding the gases and making them very light. As the smoke cools it falls down to the floor.

At the Chicago Exhibition a Krupp cannon was exhibited which when fully charged could hold 253 lb. of gunpowder. When fired it could throw a shot of 473 lb. weight a distance of twelve miles; the shot in rising attained the great height of four miles.

The force required to hurl this ball came entirely from the great bulk of gas which was produced by the quick combustion of the gunpowder.

Practical Application to Mining.

Many attempts have been made by the use of the lime cartridge and mechanical wedges of various designs to abolish explosives from our mines, but so far they have not met with success.

Explosives are largely used in the driving of stone drifts and in many cases in getting the coal and ripping the gate roads. Between 40,000,000 and 50,000,000 shots are fired annually in the mines of this country, the amount of explosive used being nearly 25,000,000 pounds.

Mining explosives are divided into (1) Low Explosives, (2) High Explosives.

Low explosives, examples of which are gunpowder and Bobbinite, may be fired by simple ignition and do not require detonation.

FIG. 89.—Low tension detonator.

High explosives, which consist of an explosive compound, sometimes alone and sometimes mixed with other substances, can only be fired with a detonator.

Detonators are copper cylinders containing a mixture of fulminate of mercury and potassium chlorate. They are made in various sizes and strengths. They may be fired by means of a fuse or electrically. In fiery mines the electrical method must be used. Electrically fired detonators may be (*a*) Low Tension or (*b*) High Tension detonators.

In the former (Fig. 89) a current of low voltage but fairly large amperage is used.

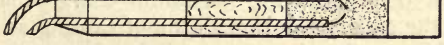

FIG. 90.—High tension detonator.

The wires inside the detonator are connected by a bridge of platinum wire which is placed in position in the priming composition of the detonator. The free ends of the wires may be attached, by means of a cable, to an electric battery or small portable dynamo worked by hand, and on the current being applied the platinum bridge, being a bad conductor of electricity, gets sufficiently hot to ignite the priming composition—an easily ignited mixture—which

in its turn fires the fulminate of mercury. The resistance offered by the copper casing of the detonator causes a severe shock or concussion which is communicated to the explosive and helps in its decomposition.

In the latter (Fig. 90) a current of high voltage but small amperage is employed, and the priming composition is ignited by a spark passing across the gap left at the inner end of the wires.

Detonators, although small, contain sufficient explosive to shatter a man's hand, and as fulminate of mercury is rather unstable, they should be handled very carefully and on no account be played with, or pulled to pieces. A number of deplorable accidents have happened from this cause.

Permitted Explosives.

It is required by the Coal Mines Act that in mines where gas has been found within the previous three months in such quantities as to be indicative of danger, and in mines which are dry and dusty, only explosives which have passed certain official tests shall be used.

These tests are now carried out at Rotherham, Yorkshire, and are briefly as follows :—

Charges of explosive are placed in a steel cannon and fired into a gallery containing an explosive mixture of air and gas, no stemming being used.

The cartridges do not fit the bore of the gun accurately but have an air space of more than $\frac{3}{8}$ inch at the top.

The test determines the maximum charge that can be fired into the gallery five times without causing an ignition.

In addition to the above, a test in a mixture of coal dust and air is employed.

Method of Stemming and Firing a Shot.

It is assumed that the shot is to be fired in a mine where permitted explosives must be used.

After drilling the shot hole, which must be of a given size to comply with the Coal Mines Act, the requisite amount of explosive, which is in the form of cartridges, is pushed into the hole by means of a wood, brass, or copper

rod or stemmer. The detonator is fixed in the last cartridge in the manner shown in Fig. 91 and in Fig. 92.

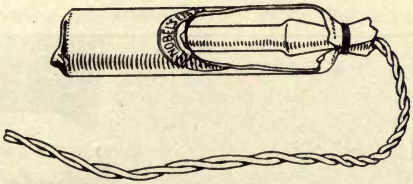

FIG. 91.—Showing method of fixing detonator in explosive.

The hole is then carefully stemmed with clay or some non-inflammable substance, the operator holding the detonator wires taut with one hand and pushing in the stemming by means of the "stemmer". The stemming is at first lightly tapped with the stemmer and with increasing force as the hole becomes filled.

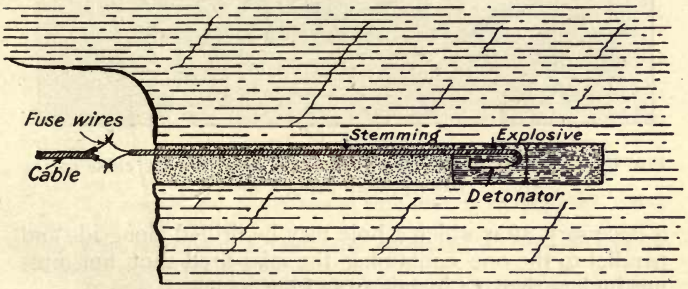

FIG. 92.—Showing method of fixing detonator in charge, and method of attaching cable to detonator wires.

The detonator wires are next attached to a long cable which in turn is connected to the electric battery or exploder and the shot is fired.

Miss-fire.

If the shot should miss-fire the detonator wires must be disconnected from the exploder and TEN MINUTES

allowed to elapse before approaching the shot. The cable may then be examined and another attempt made to fire the shot. If it again misses fire a further TEN MINUTES' wait

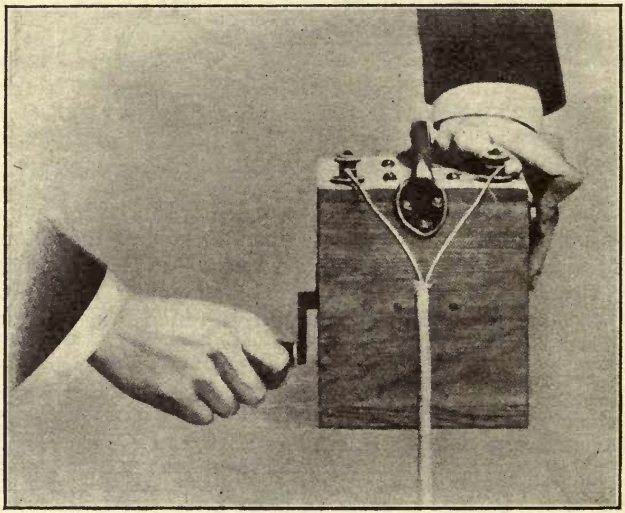

FIG. 93.—Photograph showing method of attaching the cable to the battery when firing a shot.

is necessary, after which a hole may be drilled alongside and parallel to the one containing the miss-fired shot, but must not be less than 12 inches away from it.

Accidents Due to the Use of Explosives.

It is pointed out in the Second Report of the Royal Commission on Mines, published in 1909, that during the years 1896 to 1907 there were thirty-five explosions attributed to shot-firing, causing the death of 377 persons. During the same period 308 persons were killed by accidents with explosives. In 1911, 38 persons were killed and 503 injured by accidents with explosives, and in 1913 the totals were 35 killed and 1324 injured.

An analysis of these accidents leads one to the conclusion that many of them are preventable if proper care is exercised and if regulations are fulfilled.

The following are some of the more frequent causes of accident:—

Firing by electricity when persons are at the shot-hole.

Not taking proper cover or refuge when firing the shot.

Hang fires and returning too soon to the shot-hole, ramming or stemming the charge.

Striking unexploded charges when removing *debris*.

Playing with detonators.

It is very important that the explosives in Coal Mines Order[1] should be carefully studied by all who expect to be engaged in any way in shot-firing operations or to have anything to do with the handling or use of explosives in or about mines.

QUESTIONS.

1. Draw up a list of the substances containing fixed oxygen which have been used in connexion with the experiments of this book.
2. How could you put the free oxygen of the air into bondage with phosphorus?
3. What is meant by saying that an explosive burns by its own oxygen? Mention a substance which will not burn by its own oxygen.
4. What explosives are used in your pit? Is there any danger to the safety of the pit as a whole by their use?
5. Is it possible for gunpowder to burn with no air present? Give reasons for your answer.
6. What is meant by a "permitted explosive"? Give reasons for the use of explosives in mines.
7. Describe the following blasting processes: (1) Placing the charge in the hole; (2) the stemming of the hole; (3) the firing of the charge; (4) the effect of the firing on the coal, rock, and air.
8. When shots are being fired what precautions should be taken by the firer and others adjacent to him?

Wyman & Co., price 2d.

CHAPTER XII.

DIFFUSION, OR THE MOVEMENT OF GAS PARTICLES.

In considering diffusion as the cause of the mixing of gases, let us take a lesson from the Tables giving the composition of air and of coal gas.

At whatever place the air is collected it is found to contain oxygen and nitrogen in the proportions stated on p. 37. These proportions do not vary whether the air is deep down in a mine or high up on a mountain. Moreover, the proportions are the same whether we deal with a cubic foot, a cubic inch of air, or any other amount.

Now an oxygen particle is heavier than a nitrogen particle by one-seventh of the weight of the latter, and yet these two gases are always mixed in the same proportions in air, at all heights and depths. The lesson to be learnt therefore is that given time gases will become uniformly mixed despite any difference in weight.

Let us consider coal gas. If the sample whose analysis is shown on p. 155 had been taken from any other part of the town's gasholder, it would have shown the gases mixed together in the same amounts. No one would be prepared to say that every cubic foot of the gas as it leaves the heated retorts containing the coal from which it is made, has the composition there given, but whatever its composition before it enters the gasholder, when there it all mixes uniformly together and so becomes of the same composition throughout. Many of the gases in coal gas are of different densities, but you do not find the heaviest at the bottom of the gasholder and the lightest at the top. If this were the case then hydrogen, being the lightest, would be altogether at the top, and occupy about half the gasholder

(see percentage composition on p. 155), then the heavier gas —marsh gas—would come as a thick layer, the other still heavier gases would be as layers underneath. If the foregoing were true, it would follow that when the top gas was drawn off it would have no lighting power, there is no luminosity when burning marsh gas and hydrogen. Stirrers would have to be put in the gasholders to mix the gases, but as gas particles are capable of moving and roaming they mix themselves together uniformly. The gas particles do not collect together in crowds of their own kind, but all varieties are represented and in the same proportion however big or small the crowd may be. They arrange themselves in the gasholder so that every cubic inch of space is filled in the same proportions.

Experience.

Consider a stream of *white* smoke, issuing slowly from a chimney on a day *free from wind.* The smoke, and the gases mixed with it, will steadily spread in the surrounding atmosphere, and in time the smoke will not be seen, its particles have spread uniformly in the atmosphere around by their own movements.

A black cloud of smoke would behave differently ; its particles are bigger and heavier than white smoke particles. It would fall to the earth almost as a whole ; this is not diffusion but falling by weight.

The gases which come out with the smoke in either case are not visible and their particles never fall to the ground but mix with the air. This mixing will go on long after they have lost the rush which they have on coming out of the chimney. It goes on because the individual particles never lose their power of moving; ceaseless movement is a part of their natural gifts. This ceaseless movement, which all gas particles possess, in time makes them spread out in the air ; they cannot long remain as a *swarm* of gas particles, but are bound to distribute themselves.

Stagnant Gas.

It should be thoroughly realized that there cannot be such a thing as stagnant gas, even the heaviest gas we have in mines—carbon dioxide—consists of moving particles and cannot therefore become stagnant. Its heavy particles

move slowly away from the bottom of disused shafts and wells. Suffocation has been caused by accumulations despite this slow movement. If gas appears to remain in a hole, or a dead end, or a corner, for days it is not because it is stagnant, the gas is moving—diffusing—out of the place but gas is at the same time feeding into the place, hence one is liable to reason wrongly and say the gas is stagnant. Movement of the particles goes on even when the gas accumulation is not affected by the rush of the ventilating current, and also in places where the current has become extremely weak. That part of the gas which has diffused out into a ventilating current is swept along by, and with it, its particles still have a motion of their own, but the current sweeps them along by its superior force.

Illustration.

Any place, e.g. train, tram, hotel, may be filled right throughout the day, but no one would assume that the same people have occupied it all the time. People have entered and departed and thus the supply has been kept up. It is the same with gas particles in any space other than a gas-tight one.

Fig. 94.—Liquid floating on water.

Liquids, other than oils, mix amongst each other very slowly, but on account of many liquids being coloured, they afford an experimental way of showing to the eye that mixing does take place. The majority of gases are colourless, and so it is not as easy to show that they diffuse amongst one another.

Experiment.

Half fill a gas cylinder with water, and then pour gently a thin layer of oil on its surface. Leave the liquids for any length of time and they will remain as two unmixed columns (see Fig. 94).

Repeat the experiment, but instead of using a layer of oil pour gently a layer of coloured methylated spirit—coloured by a drop of ink—on to the water surface. Make a mark on the cylinder where the two columns meet. Leave the apparatus and notice the change which goes on at the two surfaces in contact.

Mineral, animal, and vegetable oils will not mix by their own movement with water. Despite the fact that the particles of water and oil are moving slowly, each remains with its own kind of particle; they will not, or cannot, diffuse.

In the case of water and methylated spirit, their particles will move into each other's territory, i.e. diffusion will take place, as is evidenced by the alteration of colour at the two surfaces in contact.

The advantage which a liquid possesses in being coloured is something like the advantages a gas possesses in having an odour. The first one helps by appealing to the eye and the second one by appealing to the nose. When a puff of any gas, be it coal gas or fire-damp, passes into the air the swarm of particles making up the puff soon begin to move apart from one another and so spread out in all directions, and whether it be a hall, a bedroom, or a mine, they will in time be present in every part of it; unless sucked out by a ventilating current.

A Comparison.

If two solids are placed in contact their particles will not mix by their own action. Liquid particles will mix slowly by their own movement, with a few exceptions, chiefly oils. Gas particles mix by their powers of movement and there are no exceptions.

The diffusion of gas particles through walls which are apparently gas-tight shows their extreme smallness. Walls of brick or stone are not easily made air-tight.

Experiment.

Fit up a porous pot with a well-fitting stopper through which projects a glass tube. Attach to the tube by a piece of rubber a U-tube containing some coloured water in the bend, and lower the porous pot into a jar of carbon dioxide (see Fig. 96), or up into an inverted jar of hydrogen or coal gas (see Fig. 95). Notice if the level of the water in the U-tube is slowly altered.

The U-tube used may be a smaller one than those shown in the figures; the one made for experiment on p. 49 will do.

The following actions go on during the experiment: particles of gas in the jars are passing inwards through

the pores of the pot and particles of air are passing outwards through the pot. In the experiment of Fig. 95 more hydrogen or coal gas particles get in than air particles get out; therefore overcrowding goes on in the U-tube, and the

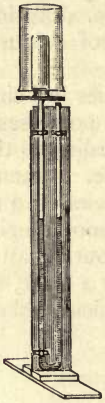

FIG. 95.—Showing the method with hydrogen or coal gas. U-tube on stand.

FIG. 96.—Showing the method with carbon dioxide. U-tube without stand.

water moves down the left arm to accommodate the extra particles. In the case of carbon dioxide the water will rise in the left arm of the tube owing to more air particles getting out than carbon dioxide particles are getting into the tube.

Experiments.

1. A bottle or gas cylinder filled with any one of the following gases, (*a*) coal gas, (*b*) carbonic acid, (*c*) hydrogen, may be shown to have lost its contained gas after a lapse of time by the use of a lighted taper. Keep (*a*) and (*c*) inverted.

2. If any of the three gases mentioned is shut up in a porous pot by a rubber stopper, then opened later and tested by a lighted taper, it will be found to have disappeared.

3. Place a beaker on a scale pan and balance it when filled with carbonic acid gas (Fig. 13, p. 34). The beaker should be dry and no liquid allowed to fall in from the carbon dioxide apparatus tube. Notice the alteration in the balance after the lapse of a few minutes.

The gases hydrogen and coal gas are lighter than air, and so the air tends to fall into any vessel containing them and force them out. In order therefore to show that diffusion goes on the cylinders must be held upside down. In these circumstances the air tends to shut the gas in the cylinder, but cannot on account of its particles possessing movement.

With carbon dioxide, as it is heavier than air, the vessel must be kept upright; otherwise if turned upside down it would fall out as a whole. By preventing falling out getting out individually, by diffusion, can be proved.

The explanation of the action in Expt. 2, p. 196, is based upon the fact that you cannot shut up a gas unless it be in a special gas-tight vessel. A gas will get through a porous vessel; only by glazing it or filling up its pores could it be made gas-tight.

Experiment.

Take two gas cylinders which fit well when their mouths are in contact, one cylinder being above the other. Calling L the lower and U the upper cylinder, fill L with air and U with coal gas. Put them one above the other and apply a light in 5 minutes. Repeat experiment with the cylinder containing coal gas below the cylinder containing air.

When the air is under the coal gas, then any mixing which has taken place is due to true diffusion—the mixing which has occurred by the particles' own unaided movement is diffusion. In the case of the air being above, it would tend, by its greater weight, to mix with the underlying coal gas, and such action is not true diffusion. Pulling a particle down is different from the particle moving down by its own action; it is weight that does the pulling down, and does it quickly, whereas the particle's roving power is a slow movement.

The particle by its own movement may move up and down, but weight never pulls up a thing after pulling it down.

SPEED OF DIFFUSION AND HEAVINESS OF GAS PARTICLES.

Gas.	Relative speeds.	Relative heaviness.
Hydrogen . . .	3·8	1
Marsh gas . . .	1·3	8
Air	1·0	14½
Carbon dioxide . .	·8	22

It will therefore be seen from the second and third columns that the heavier a gas particle is the slower it diffuses.

Experience.

You have no doubt noticed that a flower-pot shows moisture on the outside when a plant in it is kept well watered. The water particles pass through the pores—fine tubes—of the pot. If the pot is kept in a saucer of water the water will rise in the material of the pot as well as in the soil.

Ask yourself why tea-cups are glazed, and why badly glazed jam-pots or fancy flower-pots are not quite watertight.

Just as water particles pass through the pores of an unglazed vessel, so will air particles get through bricks and keep gob fires on the smoulder. The smell of cooking is not an easy thing to confine to its proper room in a house or hotel, the particles which smell overcome all obstacles to diffusion.

The experiments also point out how difficult it is to shut up a gas; brick walls enclosing a waste heap may let out some gas, and let in some air, on account of the porosity of ordinary bricks.

The teaching of the experiments in this chapter is of great importance to those engaged in mining. In mines there are many sources of different gases, some of which are inflammable and therefore dangerous from an explosive standpoint, others non-inflammable but dangerous from a health point of view. One cannot help but regard the mine as a big mole run deep down in the earth with two borings or shafts, one for taking in air and the other for clearing out the air after mixing with mine gases. Thus the ventilation current helps to sweep out all gases, but at the same time it is diffusion which

helps to equalize the composition of the air of the workings. Whether it be carbon dioxide given out by men and animals breathing, inflammable gas given out by blowers, or from the face of the coal or from roof, all are mixing with the air of the ventilating current. In this way all objectionable gases get diluted; they do not accumulate around the place or man which are their sources, and so this natural action of diffusion promotes health and safety. As soon as fire-damp has diffused into sufficient air to reduce it to less than $5\frac{1}{2}$ per cent, there is no fear of an explosion : see figures, p. 107.

QUESTIONS.

1. A gas tap accidentally left open in the kitchen was detected by an occupant of the attic. Explain how this was possible.

2. A motor-car passing down a street left an objectionable odour behind which finally disappeared. Explain how it was lost to the sense of smell.

3. A swarm of bees leave a hive and spread over the surrounding country, but return again one by one at night. What part of this action is similar to the diffusion of gas particles ?

4. A cup of tea has a small amount of milk poured into it and then left for a considerable time. Can you explain why it finally has a uniform appearance ?

5. The amounts of carbon dioxide and marsh gas in the return air of a mine was ·1 and ·75 per cent respectively. Do you think these percentages would be the same near the source of the gases ?

6. In a manufacturing town on a windless day large volumes of smoke were seen passing into the air, but later on the air had cleared. What might have happened to the smoke ?

7. What do you mean by the word diffusion ? If a gas had no power of movement could a leakage find its way all over a house ?

8. What processes going on in Nature help to make air uniform after its being fouled in several ways ?

9. Bricks are of two kinds—with and without a glazed face. Through which do you think a gas or a liquid is the more likely to pass ?

10. In a public hall smoking is permitted on the ground floor only, but in the balconies it is noticed that the air is uniformly hazy with smoke. Explain how this uniformity is brought about.

11. Use the facts of the foregoing question to define the following : (1) uniform density ; (2) varying density ; (3) the movement of particles.

CHAPTER XIII.

SUBSTANCES AND THEIR CHANGES.

THE substances which make up this world may be divided into two groups; those which attack one another at once when they come together, and those which require heating to start an attack upon one another.

1. Substances which with no previous heating attack one another when they come together, and after the attack hold one another in bondage :—

Iron, oxygen, and water, as in rust.

Mortar and carbonic acid, as in its hardening.

Gob waste and oxygen.

2. Substances which when slightly heated are attacked by oxygen, and after the attack hold the oxygen in bondage with their constituents :—

Coal gas. Coal dust. Petroleum.

Let us consider first a few well-known substances which attack one another without any heating and produce a new substance as a result of the action.

Experience.

Iron exposed to the air undergoes a change which is called rusting ; the substance produced by the action is called "rust".

The new thing produced, rust, should receive attention because it differs very much from the substances of which it is made. Let us tabulate some of these differences under their respective heads :—

Iron.	Oxygen.	Moisture.	Rust.
Grey.	Colourless.	Colourless.	Reddish-brown.
Tough solid.	Gas.	Vapour.	Friable solid.
Air attacks it.	—	—	Air no action on it.

What is it in the air that attacks the iron? Moisture we know is always present, and this, along with the oxygen, set up the attack. The iron is solid and gives us the impression that it is passive in the action, but such is not the case. In all changes which produce a new substance, the particles of each substance are joining in the attack, but not necessarily all with the same vigour.

Rust then differs fundamentally from its constituents. It is necessary to emphasize the fact that the new substance consists of all the three things concerned in the action: iron, oxygen, and moisture. If we look at rust it certainly does not suggest there is moisture in it, it is quite dry. It is one of the most difficult things to realize that when substances attack one another they become fixed or united together, and each one loses its own individual characteristics, and their union is so strong that it is difficult to break them again apart. Particular attention should be paid to the idea of the substances becoming fixed or united together, it is quite distinct and different from the idea of being mixed together. Nature takes the iron, oxygen, and moisture, unites them together, and the new substance, rust, is not only different to look at but seems fundamentally different from the original materials.

"There are agents in Nature able to make the particles of a body stick together by very strong attraction."—SIR ISAAC NEWTON.

Analogy and Experiment will help an Explanation.

Old iron structures such as fire-grates, fly-wheels, grates, broken cast-iron pipes, baths, kitchen boilers, iron window frames, etc., are collected by the old iron merchant and sent where iron is smelted. They all go into the melting pot and lose their individuality, and as things they could not be recognized in any new structure made from them.

The particles of iron in the old structures are loosened from one another by the heat applied, and the solid becomes a liquid. The particles of solid iron are said to be held together by the force of cohesion, of which there is very little in the liquid state. Heat therefore seems to overcome this force, and as the liquid iron loses its heat and again becomes solid the force of cohesion again acts; it should be noticed

that heat is capable of overcoming a force which holds particles together. Suppose this old iron had got mixed with some sulphur, popularly known as brimstone, and the two things had got melted together. On cooling there would not be a lump of iron and a lump of sulphur to be seen, but a new substance quite unlike the sulphur and the iron from which it was made.

Experiment.

Mix well together equal weights of iron filings and flowers of sulphur. Notice that no change goes on, but that the two constituents can be seen lying side by side. If you have a magnet separate the iron filings from a part of the mixture, and notice that no change has occurred to the filings or to the sulphur.

The magnet passing through the mixture withdraws the iron and leaves the sulphur.

Continuation of the Experiment.

Place some of the mixture in a test tube, say a layer of $\frac{1}{2}$ inch. Heat it in the Bunsen flame gently (see Fig. 97), and carefully notice any action that happens.

The sulphur melts and darkens and then a bright red glow passes through the mixture. When the glow starts remove the tube from the flame and notice that it does not cease, it goes on without any outside heat. This fact is of great importance. The outside heat is used in melting the sulphur, i.e. overcoming the cohesion of its particles, and in heating up the iron and sulphur to the temperature required for their attacking each other. As soon as the red glow appears it means that the iron and sulphur particles are attacking each other, and in the attack sufficient heat is made to produce a red heat. Whilst this glow is proceeding the iron and sulphur are losing their individual existence, they are becoming locked together by a force, called chemical force, and the glow is a proof it is acting vigorously.

Conclusion of the Experiment.

Break the tube and look at the cooled substance, it is very much unlike sulphur, harder than it, but less hard than iron. It

is bluish-grey in colour, and a magnet has no action on it even if the substance is powdered. Notice it has a uniform appearance which the original mixture had not. Is it like the original components?

A new substance has been formed and its name, iron sulphide, suggests its components which as free individual substances have disappeared.

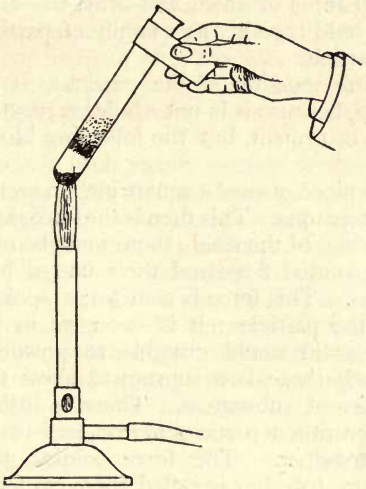

FIG. 97.—Heating the mixture in a test tube so as to bring about a change.

Here, as in the formation of other new substances, there has been an attack by the particles on each other, producing the fire of the action, and the particles of the two original substances have become held together by chemical force, a force much stronger than cohesion. When chemical force is acting between substances heat is being produced; on the other hand, heat acting on substances may be overcoming chemical force. One iron particle locks itself to one sulphur particle, and if in the experiment an excess of one substance is left in the tube it shows we have not been

skilled enough to obtain an equal number of particles of sulphur and iron.

If we had weighed out $1\frac{3}{4}$ times more iron than sulphur this condition of equal number of iron and sulphur particles would have been realized.

In all these actions between bodies it is really a case of the particles attacking one another. In the case of rust formed in the air two particles of iron are attacked by three of oxygen and three of water, and after the attack they all continued to hold together as a family of particles, i.e. as a compound particle.

The holding together of the particles is not an easy thing to grasp, because it is not a holding together by hooks, screws, nails, or cement, but the following illustration may help.

To break a piece of steel a square inch in section would require a pull of 30 tons. This then is the force required to tear apart the particles of the steel; there must be many particles in the two separated faces and their united holding power equals 30 tons. This force is sometimes spoken of as the cohesion of the particles; it is strongest in solids, in its absence the solid would crumble to powder. Compare rust with steel, these two substances show that cohesion differs in different substances. There is little cohesion in rust, yet its constituent particles of iron, moisture, and oxygen hold firmly together. This force holding particles of a different nature together is called chemical force, or attraction; it wants distinguishing from cohesion, for the latter may be overcome by pulling at a thing until it breaks, whereas chemical force cannot be overcome in that way.

Ice, Water, and Steam.

These three substances are actually three different conditions of one substance, and if their changes into one another were less well known to us it is possible we might believe them to be different substances.

There are well-defined differences in them; one is a solid, easily broken and capable of being moulded; the other is a liquid of a light blue colour, and dissolves many things; the

last is a vapour that is quite invisible. Why should the same thing appear in three different states?

The differences may be connected with the amounts of heat in them, for we all know there is more heat in steam than in water or ice. Such a fact suggests that when heat is run off a body, or put into a body, its properties change. This is a very important fact, and so we may regard the changes in a substance to be influenced by losing or gaining heat.

The differences may be influenced by the varying distances between the particles and by the size of them.

The distance between the particles of steam must be greater than between the particles of water or ice, inasmuch as steam occupies 1650 times more space than the water from which it is made.

We may picture each steam particle as free from any or all other steam particles, but as steam passes to water three or four particles may unite together and remain united as long as they are water, and in becoming ice there may be a further locking together of particles. This union of particles along with a giving up of heat may be entirely responsible for the different properties of the three substances. It is quite true that when particles become associated together, or driven apart, there is always a change in the properties of the substance. It is known that the particles of water are made up of groups of steam particles, i.e. that two, three, or four particles group themselves together when steam changes to water and remain grouped together.

It is now necessary to go a step further in this idea of the properties of a substance depending on the number of particles holding together as a group. Is a particle of water, steam, or ice, a simple thing, i.e. is it made of still smaller particles? Are there smaller particles making up a particle of water and are they alike or unlike?

Supposing some steam particles were heated to a very high temperature each steam particle would break up into one oxygen and two hydrogen particles, the latter still united together. Here then heat simplifies the steam particle and resolves it into its simple and final constituent particles. These particles are quite different from steam particles; oxygen will burn up most things, hydrogen will

easily burn with flame, whereas steam can do neither ; on the other hand, it will stop a body burning. It is therefore important to remember that when simple or dissimilar particles group themselves together, heat is concerned in the grouping, and the grouped particles have different properties from the ungrouped particles.

All the substances of this world consist of particles. Some very active, restless particles, e.g. oxygen, are always attacking other particles, and in this way changes are always taking place. In these changes heat is in some way concerned ; when oxygen is an attacking agent heat is always produced. This is even the case in rusting, but as the action goes on slowly the heat is produced in very small quantities.

When a little heat has to be *supplied* to start an action there is always as the action goes on some more *produced.* In lighting the gas or the fire very little heat is required to start the action, and after this all the heat produced is due to the attack of the oxygen of the air upon the gas or coal.

In this attack by oxygen particles upon the particles making up gas and coal, new substances are produced, due to new grouping of the particles taking part in the action. This production of new substances is evidenced by the loss of smell by the gas and in the case of the coal by the substances which go up the chimney, and the ashes left in the grate. The size of the particles of substances and the changes they undergo from visibility to invisibility is expressed in Tennyson's lines :—

> The million millionth of a grain
> That, ever vanishing, never vanishes.

The Militancy of Oxygen.

Oxygen particles are very energetic, and either feebly or strongly they will attack most things. This attack in many cases goes on at the ordinary daily temperature. In other cases, the oxygen particles require a start, which means the substances must be warmed or heated for it to carry on its actions. In either case the oxygen comes to the end of its attack and then it is a prisoner—held by the force of chemical attraction—in the hands of the substance it attacked.

Oxygen attacks at the ordinary temperature :—

The metals iron, sodium, and potassium.
Phosphorus.
Very dry coal dust.
Substances found in the gob.

At a higher temperature it attacks most things, e.g. wood, gas, coal, illuminating oils, etc.

Some substances have long been conquered by the oxygen as fully as possible and the attack is finished; sand, water, rust, carbon dioxide, represent substances which are no longer open to further attack by oxygen. Whatever there is in these substances besides oxygen it has been attacked, and come to its limit as regards taking up oxygen.

Oxygen is the carrier of the fiery cross, and if it gets an opportunity with those bodies we call combustible there is soon flame and heat. It can attack all substances containing carbon and so produces carbon dioxide gas, the great food of plants. Our blood and bodies are a prey to oxygen, so in time we become plant food.

It is the ease with which many substances are open to attack by others that there is danger in the mine.

Substances Made of One Kind of Material.

The scientific man will tell us that out of eighty *simple* substances all the various materials of this world are made, and by a simple substance is meant one made only of one kind of particle. No one has ever succeeded in breaking up any one of these simple substances into two different substances, or of getting out of it anything other than itself. These simple substances are called Elements; several are gases, few are liquids, and many are solids. A list of the commoner ones is given here :—

Gases.	Metals.		Not Metals.
Oxygen.	Iron.	Tin.	Carbon.
Nitrogen.	Copper.	Silver.	Sulphur.
Hydrogen.	Zinc.	Gold.	Phosphorus.
	Lead.	Mercury.	

The thousands of substances in this world which are not

simple are all made up of two or more of these eighty simple substances. These eighty elements are the foundation of all substances, and it is by their particles joining and holding together in different numbers and different ways that we have countless different substances. Nature works something like a builder does, each has things with which to work. Nature has elements, a builder has bricks, and just as the builder may fix his bricks to produce different structures from a simple brick wall to a complicated palace, so Nature fixes the particles of her elements, two or more together, to produce a simple thing like water or a complicated thing like coal.

It may be difficult to realize that when particles are joined together by chemical force there should be so great a change in their properties. Let us consider a few well-known and striking changes. The plant in all its parts—and the flower is often a very beautiful part of it—is made up of materials which it draws from air and soil alone. These materials are the raw materials of the plant, and by chemical force acting on the particles of these materials, rearranging them in different ways, it produces all the glory of the plant. Science says that this great alteration is due to a new arrangement of the particles, which in their original state formed part of the invisible air or a part of that uninteresting, and not very beautiful, substance called the soil. Chemical force is therefore the magician's wand which links particles together in various ways and so makes them appear to our eyes and other senses as very different things.

Whoever would have thought that the black stuff which comes out of bread when it is badly toasted is in the white substance called flour. This tells us then that chemical force which joins things together can turn black into white, and when heat overcomes this chemical force it can turn white into black. The black and white of course are different substances.

A chemist can take this black substance which is got out of bread, and by melting it and tightly pressing it together in a suitable vessel at a very high temperature, near the melting-point of iron, turn it into a diamond.

He adds nothing to it, nor does he take anything away,

but the heat rearranges the particles originally forming the black material, and that which was black and opaque becomes brilliant and transparent. It is no more wonderful than the aniline dye manufacturer, who starting with tar, as is used in street paving, turns it into beautiful dyes.

Changes in Electricity.

The changes which go on in substances when by their acting upon one another new substances are produced is no more remarkable than the changes which electricity may undergo.

Consider a tram-car driven and illuminated by electricity. The same electricity that leaves the overhead wire enters the mechanism of the car and sets it in motion is also converted into light and heat. Here is a wonderful transformation of electricity into motive power, heat, and light; new creations, as it were, from the original one.

Light and heat thus have their origin from electricity, and other remarkable changes, such as friction producing heat and heat producing electricity, are of constant occurrence.

It is just as difficult to see the causes or way by which electricity changes and becomes heat as it is to see the causes or way by which substances change when they act together and give rise to new substances.

Practical Application to Mining.

In the previous pages of this chapter it has been explained how changes are continually taking place due to the constant state of war which exists between the various substances forming the world.

Those who work in mines may find in their daily experience many examples of these changes. When lamps burn, or men breathe, the strife between the oxygen of the air and the carbon of the lamp oil or the human body results in the formation of a new substance called carbon dioxide. This substance is composed of carbon and oxygen but possesses the properties of neither, which will explain what often puzzles beginners—why a substance containing so much oxygen is dangerous to breathe. It should be

remembered that in the dark passages of the mine there is no compensating change as on the surface, where the action between carbon dioxide and plants in the presence of sunlight results in the absorption of carbon dioxide and the giving out of oxygen. The change is entirely one of production due partly to burning and breathing and partly to action between the coal and the air, and if it were not for the fresh air which is constantly being circulated through the mine the atmosphere would soon become so changed as to be unfit for breathing.

When explosives containing nitro-glycerine are imperfectly detonated or allowed to burn without detonating, the constituents of the explosive, particularly the oxygen, attack each other, and the result is the formation of new gases which are very dangerous to breathe.

When explosives of any description are fired change takes place and the solid explosive is changed into gases which have different properties from those of the solid from which they came.

Further examples of familiar changes which occur in mining experience are :—

1. The action of water on steam boilers. A hard crust of scale is often formed on the inside of boilers by the impurities contained in the feed water. To remedy this further impurities are often added to the water with the object of setting up action between the various impurities, resulting in the formation of new bodies with less injurious properties.

2. Grease in boilers or engine cylinders may be a means of setting up chemical action, causing corrosion and pitting of the boiler plates.

3. Tubbing used in pit shafts and pipes conveying water to and from pumps are often acted upon by substances contained in the water. Sometimes the pipe may get so soft that it can be cut by a knife.

4. Changes occur in the Leclanche cells often used for providing the electricity for signalling purposes in mines. The zinc rod is eaten away and the liquid in the cell becomes entirely changed in the course of time, having entirely different properties.

Still further examples of these wonderful changes will doubtless present themselves to the observant student as he goes about his work.

QUESTIONS.

1. Ordinary air may be turned into liquid nitric acid by electricity, therefore both are made of the same substances. What name would you give to this change? Such changes of substances being turned into other different substances are very common; try and mention some.

2. Give reasons for saying that new things are, or are not, produced when the following actions occur: (1) iron is rusted; (2) wood is burnt; (3) electricity is passed through an electric lamp; (4) water is boiled; (5) gunpowder is exploded.

3. What is meant by the by-products of coal? If there be a by-product plant in your district, try and find the names of the different substances made from coal, and what becomes of them.

4. How many things are produced when petrol burns? What are the changes it undergoes?

5. When carbide of calcium is treated with water acetylene gas is formed. Why is it certain that the carbide has undergone a change?

6. Give the names of the substances into which the following may be changed, and state how the change is brought about: limestone, soil, wood, bread, oil, air, and milk.

CHAPTER XIV.

COAL, ITS NATURE, PRODUCTS, AND ORIGIN.

When coal is being burnt great changes are going on in it, and the final result is material called ashes, which are left in the grate, and a great deal of smoke, and gas, which have gone up the chimney.

Smoke and soot are two very visible things produced in the change, but they do not form the whole of the substances which pass up the chimney flue; there are invisible gases mixed with the rising smoke. These invisible gases are worth a consideration; they will bring out the value of air in the changes going on in the fire-grate.

Experience.

Attention should be given to the smoke issuing from different chimneys: factory, mine, and house. In some cases it will be found black, in other cases white.

It should be clearly realized that coming from such chimneys along with the visible smoke there are invisible gases, chiefly non-combustible ones, otherwise the smoke might be accompanied by flame. These incombustible gases are carbon dioxide, oxygen, and nitrogen. There may be a small amount of carbon monoxide in the smoke, but it is too cool and too dilute to burn at the chimney top.

The difference between black and white smoke is really caused by bad and good combustion. In the former case there is too low a temperature or too bad a draught to get good combustion, and some soot particles get through unburnt.

How Combustion is Helped.

Why is the fire lifted up by the poker? It is to let air into the interior of the fire so that combustion may be increased; the poker is also used to remove the ash which chokes up the entrances through which the air should pass.

Experience.

Take off the lamp glass of a burning oil lamp and notice the incomplete combustion, there is smoking, caused by too bad a draught. The lamp glass improves the air supply. Opening and closing the damper of the chimney gives similar effects.

Sometimes the amount of oxygen in chimney smoke may be as much as 17 per cent, but in fires stoked by machinery it may be as small as 6 per cent (see Table, p. 217); a whiter smoke is produced by the extra oxygen having been used in burning carbon particles. A white smoke means no waste of the heating power of coal, whereas a black smoke means great loss. In the City of London it is said that 76,000 tons of soot are given off annually into its air; this means a great loss of heating power.

The Smut.

That black irritating coal-flake produced when combustion is very bad, called the smut, is worth a little consideration; it is sticky, light, combustible, and acid. These are four properties of the smut which will teach us a lesson in chemistry from experience and experimental points of view. The stickiness is due to a small amount of tar in the smut, and so it collects on the surroundings of the fire-grate. Look at the back of the fire-grate and notice how it is plated over with soot, and further notice that when a big fire is burning this soot gets burnt away, and the red colour of the bricks of the fire back are again seen, so the smut is combustible. That such is the case is shown each time "a chimney gets on fire".

The smut is light; it floats on water and goes along with a light breeze of air; in this it resembles a snow-flake.

Experiment.

Take a small amount of soot and throw it on some water in a dish; it floats. Stir it up with the water and then dip in a blue

litmus paper; if the blue colour changes to red then the liquid is acid, the acid comes from the smut.

Coal contains a small amount of sulphur (brimstone) which on burning turns to an acid; in a fog of the smoky variety the eyes often smart, and the mouth tastes its acidity.

Combustible Gas Mixed with Smoke.

A fire may be almost out, or at least shows only signs of a red glow at parts, but nevertheless gas and smoke may be coming off from the coal. A fire fed by Silkstone coal often shows this state, and the following experiment may be performed.

Experiment.

Drop a lighted match on to the fire in the grate where smoke is coming off; the gas mixed with the smoke may ignite. If it does, it proves the presence in it of combustible gas.

This is a very important point. It tells us that the heat of the coal is too low in temperature to ignite the gas, but the temperature of the match is high enough. Therefore the temperature at which coal gas ignites must be reached before a flame results.

The Arrangement of a Coal Fire.

A fire which is ready for lighting usually consists of three distinct layers: a layer of paper at the bottom, then a layer of wood or chips, and a coal layer at the top. Notice that the materials are of different thicknesses; thin paper, thicker wood, and pieces of coal.

Why should there be such a series of layers? It is connected with the fact that the burning has to be started by a match which has but a very short life as a fire-giver and therefore cannot be used to ignite the coal directly.

The layers of paper and wood are sometimes done away with and "firelighters" used, as the latter are made of bits of wood and an inflammable material, and as the ignition is started by a lighted match setting on fire firstly the easily inflammable material and then the wood, the problem is much like the three layers of the fire.

The paper is easily ignited, much more easily than wood, and very quickly is all ablaze. The burning paper is sufficiently hot to ignite the wood but lasts a very short time compared with the latter. When the wood gets into action there is an abundance of heat produced, and as it lasts for some time the coal gets warmed up and finally ignites. It is not until the temperature of the coal approaches 350° C. that there is any indication of burning. The temperature at which burning takes place varies slightly with the quality of the coal, but as soon as it gets higher than 350° C. rapid action begins.

Other Phenomena of the Coal Fire.

As the coal, particularly a soft one, gets hot it cakes, or becomes pasty, and at these pasty places "blowers of gas"

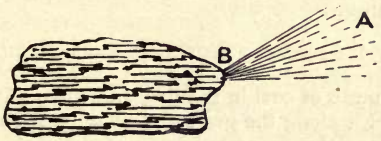

FIG. 98.—A blower.

will be formed, and as this gas issues out it will light. If the fire is very hot the gas may be ignited throughout from A to B.

The flame will often be limited to the end A and not be burning its full length, AB. Gas is then being distilled off too rapidly to allow the flame striking back to B, and no air being mixed with it at B it cannot burn. Moreover, as the gas rushes out and expands it gets cool and this hinders its ignition.

Notice the variations in the shape of the flame and its irregularity, the orifice from which it issues varies in shape; so the shape of the flame is dependent upon the orifice it issues through. Variations of the pressure with which the gas forces itself out also influences the shape.

The flame may often be seen to be brighter at the base than at the free end; this is due to the heat of the hot coal

helping the luminosity; a heated gas burns more brightly than a cool one.

The Gases Found Burning in a Coal Fire.

The gases which burn in the fire may be divided into two groups:—

1. Those present in the coal just as it comes from the pit.
2. Those which are formed as the coal is heated by the fire, and do not exist originally in the coal.

To the first group belong marsh gas and the gas nitrogen. Nitrogen is not a combustible gas, so it does not burn in the fire, whereas marsh gas burns with a very pale blue non-luminous flame. The latter gas may often be seen to take fire when a piece of coal splits along the grain by the heat of the fire. Hydrogen only occasionally occurs in coal; if present, it would burn with a colourless non-luminous flame.

Experience.

Watch a piece of coal in the fire, and when it is beginning to burn well split it along the grain. Very often a pale blue flame will run between the separated faces of the coal; this is marsh gas burning. Very occasionally it may be hydrogen which has a colourless flame; it is difficult to distinguish between it and marsh gas by their appearances when burning.

The second group comprises coal gas and carbon monoxide. Coal gas is a mixture of different gases (see p. 155), and when burning is easily recognized by the familiar yellow flame; it is seen in the fire as soon as the coal gets hot enough to decompose and form the gas. The yellow part of the flame is due to the burning of a gas called ethylene; the burning of marsh gas and hydrogen help to form the blue part of the flame.

Carbon monoxide gas occurs in fires as pointed out on p. 111. It is formed in two ways on an ordinary coal fire. In the first place the decomposition of the coal by heat produces a small quantity of carbon monoxide, and this occurs when the fire is not entirely red-hot. When the fire is red-hot throughout carbon dioxide is being produced, but

before it leaves the red-hot area it is quickly robbed of half of its oxygen and becomes carbon monoxide (see p. 113).

Carbon dioxide occurs in neither group because it is not found burning in a coal fire; it is incombustible. Of course carbon dioxide is formed, and as long as it is being formed the coal or coal gases are burning, but as soon as their carbon has turned into carbon dioxide their career of burning is ended.

The following figures show the gases and the proportion in which they are to be found in a well-burnt flue gas:—

Carbon dioxide .	11·2 per cent.
Oxygen . . .	8·4 „
Carbon monoxide .	1·1 „
Nitrogen . .	79·3 „
	100·0

Nitrogen is in the biggest quantity because it is plentiful in the air which supplies the oxygen for combustion. The nitrogen does not undergo combustion. The oxygen of the air is reduced in quantity because it is used in burning the coal, or coal gases, into carbon monoxide and carbon dioxide; the former gas is very small in amount.

The Origin of Coal.

There seems to be very little resemblance between coal and that of the vegetation of a great forest, yet it is said to have been produced gradually from trees and plants of various shapes and sizes, their leaves, roots, stems, and branches, which grew in a low marshy district with a warm moist climate (see Fig. 99). This vegetation long years ago grew, died, accumulated, and was finally covered by great quantities of rock. As a matter of fact, impressions of plants and trees, or their parts, which were being sealed up as the vegetation was rotting and before the overlying rocks were being laid down, are often found when coal is split along its layers. In a wood or coppice to-day may be seen trees which have fallen, and there is evidence that this occurred in forests of the Coal Age; the time when coal was vegetation. The roof of the coal seam also

FIG. 99.—Trees and plants of the forests from which coal was formed.

contains the upright stems of trees. Fig. 100 shows a stone cast of the stem and roots of a tree very common in the coal seams. Two most conspicuous differences between coal and vegetation are colour and compactness. These differences should not as regards the origin of coal present any difficulty to us, because the green leaves of the tobacco plant are by the tobacco manufacturer turned into various shades of brown to jet black, and by pressure they are shaped into thin layers called cake tobacco. The influences which help to bring about such colour changes quickly are very similar to those which helped in the alteration from vegetation to coal. In producing the blackening of cake tobacco the leaf is kept warm and under pressure. Coal seams in the making were at a great depth subjected to a higher temperature than vegetation on the earth's surface, and even what are now seams near the surface have been much deeper down in former centuries. The tobacco manufacturer, it is true, uses small quantities of oil to help in the blackening of the tobacco leaf, but oil is found in vegetation to a more or less extent, and so may have helped in the blackening process. Resin, which is related to oils, is found in coal.

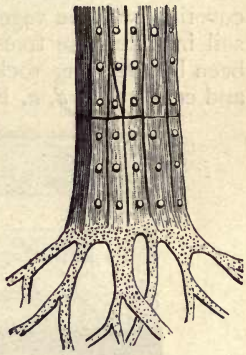

FIG. 100.

Leaves that fall on the roadsides in autumn and gradually rot as winter approaches go through many shades of colour as they become black. Sycamore leaves, almost perfect in shape but black in colour, are not uncommon to the observant walker in country lanes; the black substance of which the leaf consists is much akin to coal.

Suppose we go into a wood or coppice and at the foot of a tree clear away the accumulated remains of twigs, leaves, etc., which have fallen from the tree for many years, it will be noticed that the deeper we dig down the blacker the remains are, and the freer from any shape or form. Pres-

sure acting upon these remains would help to make them more like coal.

The middle parts of hay-stacks often show a dark brown colour owing to internal heating, and the pressure compacts the hay into layers.

Just as pressure of overlying hay compacts the underpart and makes well-defined layers, so all the original loose covering over the vegetation of the Coal Age forests; the soil in which the trees grew, and the vegetation itself have been by overlying rock material turned into layers of rock and coal (see *b*, *d*, *a*, Fig. 101).

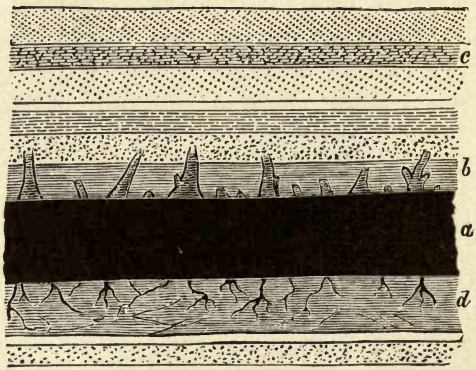

FIG. 101.—*a*, coal seam; *d*, under-clay; *b*, *c*, shale and sandstone forming roof.

The figure shows the rocks which are passed through in many pits when going from the surface to the coal seam, *a*. Under the coal is the pit floor, a layer, *d*, of "under-clay," as it is called; it has hardened into shale, and in it are found the roots of trees which grew in the forests of the Coal-forming Age. The roof of the coal seam is shown at *b*, and may be a layer of shale or other kind of rock; in it are often found stems and branches of trees.

A great depth gives a great pressure, and even at a depth of 1000 feet below the earth's surface there would be a pressure of about $74\frac{1}{4}$ tons on a square foot. This pressure acting on a mass of vegetation would in time make it undergo great changes.

This figure is arrived at in this way: a cubic foot of water weighs 62½ lbs. and rock is 2½ times heavier than water, and so we get 166¼ lbs. per cubic foot, and a column of 1000 feet of this in length and a square foot in section would weigh 166,250 lbs.

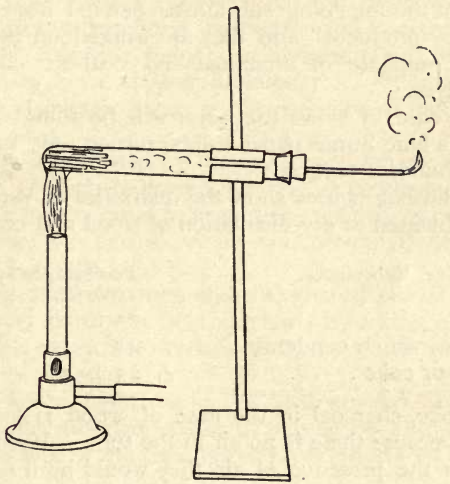

FIG. 102.—Showing the method of producing gas by heating coal or wood.

Experimental Evidence of the Similarity between Wood and Coal. Dry Distillation of Substances.

Fit a hard glass test tube (Fig. 102) with a cork, through which passes a fine glass tube. Introduce into the test tube a few bits of coal and then heat strongly in the Bunsen flame. Gas will be given off, which may be ignited at the mouth of the tube. To establish it as a gas collect some in an inverted test tube or gas cylinder full of water.

Take the vessel used for collecting the gas and, keeping it inverted, apply a light to the gas; it will burn with the familiar yellow flame.

In the water through which the gas has passed place a bit of red litmus paper; it will become blue if ammonia is present, which is also denoted by the smell. The water will contain a tarry substance, and coke will be left in the tube.

Repeat the experiments with coke and wood. The wood and coke should be in small bits.

Dry distillation means that the substance is being heated out of contact with air, and the substances so formed are distilled out of the vessel.

Some of the foregoing substances derived from coal are called "by-products," and they are worked up industrially to make sulphate of ammonia and coal-tar compounds such as dyes.

In the case of wood the water will be found acid, and therefore a blue litmus paper will be turned red; this acid is the one found in vinegar.

The following figures show the quantities of various substances obtained in dry distillation of wood and coal:—

Substances.	Percentages by Weight. Wood.	Coal.
Gas	25 to 28	14 to 17
Substances which condense . .	45 „ 50	12 „ 23
Charcoal or coke	25 „ 27	60 „ 74

The coke, charcoal in the case of wood, is left behind unburnt because there is no air in the tube. If either were heated in the presence of air they would burn completely away, except any ash left behind.

Experience.

The coke of the watchman's fire burns away leaving only an ash; trees, wood, and stubble when fired burn completely away, except for leaving an ash. No charcoal is left behind because the burning is in the open air, which supplies oxygen unlimited in amount.

If coal and wood are similar substances, then we might expect that the composition of coal gas and wood gas would be very similar. Their components given in the following table show there is similarity:—

	Coal Gas.	Wood Gas.
Hydrogen	52·9 per cent.	18 to 42 per cent.
Marsh gas	31·8 „	9 „ 35 „
Ethylene	4·4 „	9 „ 35 „

The numbers representing the per cent is the number of cubic feet of that gas in 100 cubic feet of coal or wood gas. The three gases mentioned nearly make 100 per cent.

The other gases found in *small* quantities are nitrogen, carbon monoxide, etc.

The gases therefore are the same and differ only in the amounts mixed together; hydrogen and marsh gas are abundant. Ethylene helps the luminosity of the gases; the first two burn without luminosity.

The chief interest to us is the presence of marsh gas in both the gases.

This gas is produced by the changes which go on in the wood and coal when heated, but the same change goes on only much more slowly in coal seams, which of course are cut off from air, and in wood undergoing decomposition where air is absent.

The fact that both wood and coal give off marsh gas when decomposed quickly by heat or slowly by a kind of rotting, and in each case in the absence of air, suggests they are made of the same material.

The following figures show the elements and their quantities found in different stages of vegetation and coal, and afford evidence of the transformation of wood into coal:—

Composition by Weight.

Elements.	Dried Wood.	Peat.	Brown Coal.	Coal.	
Carbon	50	58	66	84	per cent.
Hydrogen	6	5	5	5	,,
Oxygen, Nitrogen	44	37	29	11	,,

The figures tell this story: that as wood has changed to peat and then to brown and finally black coal it has lost some of the three last-mentioned substances. These three substances are all gases and therefore get away, but carbon is a black non-volatile solid, and like similar solids it cannot get away. Hence as wood changes into coal it gets richer in carbon.

Practical Application to Mining.

The teaching of the coal fire is of very great importance to those who hope to and may eventually have the management of collieries, and also to those who have to attend to the boilers generating steam at the surface of the mine.

A boiler fire badly tended or not getting sufficient air is a wasteful thing. It also causes black smoke to pour out of the chimney, blackening and spoiling the beauty of the surrounding country.

Sometimes the natural draught due to the chimney is poor and insufficient to enable the fire to get its proper supply of air. In this case if efficiency is to be obtained the draught must be improved by lengthening the chimney, or by placing a fan in the base of the chimney or by some other method of forced draught. Even under the best conditions known in modern engineering practice the driving of engines by steam generated from coal in steam boilers is not economical, only a very small percentage of the heat energy stored in the coal being available for doing useful work.

When the conditions are bad the percentage efficiency is very low indeed.

In our coal fire we get cinder or coke, and the business of making coke is a large and ever-increasing one at many of our collieries.

Coke is used in blast furnaces for the making of iron and steel and for other purposes. When coal is heated in the absence of air, or with only a very small quantity of air, it undergoes great changes. The gases are distilled off in various forms and a solid substance remains which we call coke. It consists chiefly of carbon and the ash of the coal, but sometimes contains small quantities of other substances.

When the coal is distilled in the entire absence of air the ovens used are called retort ovens. An oven consists of a chamber surrounded by a number of flues or passages. The coal is placed in the oven which is then sealed up tightly, the heat for heating the coal being obtained by burning gas in the flues.

When a small amount of air is admitted ovens of the Beehive type are employed. This oven is a dome-shaped

chamber having a doorway in front through which the coke is taken from the oven, and an opening at the top for putting in the coal. A flue and a chimney are also necessary. The opening at the top of the oven is closed by an iron lid or damper. The door in front is closed by means of bricks and soft clay, a small opening being left for the admission of air.

By-Products.

The story of a piece of coal is truly a wonderful one. In addition to giving us heat and light, and power in the form of steam, it is now possible to collect the products given off in the making of coke, and by putting them through various processes to get from them such substances as tar, ammonia, and benzol. Benzol is now largely used instead of petrol in motor-cars; from tar many beautiful colours and dyes used in beautifying our homes and our dress are obtained.

QUESTIONS.

1. Compare the result of heating wood in a closed vessel and heating it in the open air.
2. The best calcium carbide gives 5 cubic feet of acetylene gas per lb. Compare this with the amount, 10,000 cubic feet, of coal gas given by a ton of coal.
3. Explain the formation of jets of gas—blowers—and bubbles of tarry material on coal after it is placed on a fire.
4. One hundred oz. of coal left 4 oz. of ash when *burnt* in air. When *heated* away from air 100 oz. of the same coal left 90 oz. of coke. Find the amount of combustible material in (1) the coal, (2) the coke. What would be the nature of the material lost by the coke?
5. How would you show that coal gas is lighter than air?
6. Give a description of the different kinds of coal and coal seams found in your mine. Why should you sort coal into a part for selling and a part for the pit heap?

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